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THE DISTRIBUTION OF
THE LONGEST TEMPERATURE-DURATION IN A MONTH

by

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FOREWORD

This report presents the results of preliminary investigations of the distribution of temperature durations. The goal in these studies was to examine the duration-variable from different aspects and explore the problems involved in establishing a model distribution based on actual data.

A model such as this could be used to make predictions of extreme temperature duration, which is of practical significance both to the Army and in ecological studies.

Most of the work was done in the year 1966-1967, while the author was in residence at these Laboratories on a visiting associateship awarded by the National Academy of Sciences-National Research Council, Washington, D. C. It was completed under Agreement 255 between the U.S. Army Natick Laboratories and Clark University, where the author held an appointment as Visiting Professor of Geography during the 1967-1968 academic year.

The advice and assistance that was generously offered by personnel of the Earth Sciences Laboratory throughout the study is sincerely appreciated by the author.

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ABSTRACT

The statistical distribution of the longest uninterrupted duration of temperature above or below any given value was studied from hourly temperature records from 25 stations. The purpose was to examine the temperature duration variable from different aspects and to explore the problems involved in the development of a general distribution-model. Besides its value for the development of an empirical model, this information is also essential for the study of theoretical models.

The distribution of temperature durations has been derived for some types of stations and can be used to make accurate predictions. The variability in these distributions has been reduced almost to the natural limit set by the variability in time inherent to durations in nature. This was achieved by reducing actual temperature values to a uniform standard scale and by stratifying the sample of stations.

The distributional patterns of durations of high temperatures and of low temperatures are shown to be quite different from each other. The latter are considerably longer and, in winter, much more variable from year to year. Such differences must by reflected in any distribution model to be suggested, whether empirical or with some other basis.

THE DISTRIBUTION OF THE LONGEST TEMPERATURE-DURATION IN A MONTH

1. Introduction

The literature of climatology contains many references to the effect of climate on man's activity and plant growth. In most cases, however, this seems to reflect merely a recognition of a problematic and long observed relationship, rather than a real comprehension of its mechanics. Even in a relatively advanced field such as agricultural meteorology, little has been achieved in establishing biologically significant threshold values for climatic variables, though the mere existence of a relationship seems to be so obvious.

This might be a surprising situation and one hard to explain considering the constant effort made in accumulating ever-growing amounts of climatic data. The fact is, however, that most climatic data reach researchers in other fields in highly abstracted and generalized forms, such as mean values. This is unfortunate in regard to any climatic variable, but especially so when temperature is concerned because this happens to be the element on which the most detailed data are available.

In presenting data on the length of time which given values of temperature persist, an attempt is made to supply the user with a type of data that may correlate better with phenomena affected by temperature. Thus, biologists may be more interested in the duration above a given temperature than in the mere occurrence of the same temperature. Plant organs such as fruit or stem will heat or cool slowly owing to their own heat content. Therefore, a temperature threshold must be exceeded for an extended period of time to affect such organs. In a similar way, the heat capacity of an orchard may be important in frost--and presumably heat--protection (Waggoner, 1967). Other biological processes may also be enhanced or otherwise

affected by certain organs being exposed to air temperature above or below a given value for a given length of time.

Temperature duration data are valuable for the study of problems such as those mentioned above when the biological meaning of a threshold is understood. This is especially true with crop plants, whose physiology is relatively well studied. In regard to wild plants and natural vegetation, where this knowledge is largely lacking, the correlation with newly available temperature duration data may open new avenues in the investigation of threshold values.

Temperature duration data are of practical value to other users, such as the Army, which needs such data for the establishment of design criteria for materiel. Many items of military equipment have critical temperature thresholds above or below which the item fails to function properly. Complex items may have several such temperature considerations. Here also, detrimental effects are functions not only of ambient temperature, but of its duration as well. Information on the expected durations of high and low temperatures, therefore, is important in military planning and in establishing design characteristics for equipment.

Theoretically, the investigation of temperature durations can be attempted in two ways: (1) by studying the actual distribution of the durations, directly obtained from station records, and (2) through a theoretical model based on assumptions that could be justified. Not much has been done in the latter direction so far. A stochastic model has been proposed by Gringorten, based on the assumption that hourly temperature series, appropriately transformed, can be regarded as simple Markov chains with constant serial-correlation coefficients (Gringorten, 1966). The model has been suggested to apply to a variety of meteorological variables, but in regard to predictions of temperature durations, much has yet to be done to make it applicable in practice (Sharon, 1967).

The latter approach seems to be very promising and perhaps more challenging, and is also being pursued by this author. In the present study, however, the first approach is followed. Temperature durations are studied here from actual records of hourly temperature with the purpose of getting a closer acquaintance with that phenomenon and also of describing its actual statistical distribution. The distribution when obtained will serve in a number of ways. Firstly, such distributions are needed in the study of any theoretical model for verification purposes, as in the study by Sharon mentioned above. Secondly, the distributions could be found to follow regular patterns, lending themselves to generalization and the establishment of a general empirical model. The feasibility of developing such a model is the formal subject of the present investigation and in this respect this is a pilot study.

The study of temperature-durations from station records has been carried out for a considerable time in the US Army Natick Laboratories (Westbrook, 1962, 1968; Hook, 1964, 1966). The development of a simplified model was attempted that would apply to any temperature, any month, and any place in the world. This goal was not achieved as a usable tool, but some of the results that were produced could be used for further study. Mrs. J. H. Westbrook of the Natick Laboratories also took active part in the present study and her effective help is hereby duly acknowledged.

2. Definition of the Variables and of the Scope

The data needed for the present study consisted of the complete records of hourly temperature. Consequently, t-d's (temperature-durations) were defined as the number of consecutive hourly observations, all of which lie at or above (or below, as the case may be) a given temperature level. Thus a 5-hour duration above 100°F refers to an uninterrupted sequence

of exactly 5 hourly observations of 100° or more. Such a duration could be representative of an actual duration of 5 hours ± 59 minutes, or a range of 4-6 hours. Also, considering irregularities inherent in the pattern of temperature change during the day (e.g., on thermograms), a "duration" could be easily interrupted between observation times without this being reflected in the hourly record. Such interruptions may be long or insignificantly short and of no importance. On the other hand, any occurrence that does happen just at observation time might also have been momentary only, and not at all representing a whole hour.

The t-d variable as defined above is definitely strongly correlated with actual durations, but strictly speaking, it is still only an approximation or an estimate thereof. As such it is subject to an additional amount of variability relative to actual durations, measured in minutes. Of course, not much can be done in this matter; but the consequence thereof, such as those mentioned, should be borne in mind.

The variable more specifically dealt with in the present study is the longest uninterrupted duration <u>in a month</u> at or above (and at or below) given temperature levels. In the following this will be referred to simply as "the longest t-d." The words "uninterrupted", "at or", and "in a month" will be omitted, but are always implied. This means that for each single month only one duration (for each temperature level) is considered, namely, the longest one. For example, to obtain a sample of 10 values of the longest t-d above 80° in July in a station, hourly data for 10 years are required; examples can be found in Appendices A and B.

Unlike Gringorten's study, the distribution of duration for given temperature levels has been worked on here. In Gringorten's model, it is duration that is kept constant rather than temperature, and therefore conditional probabilities of

temperature values for given m-hour periods are dealt with. This may be well suited to problems specifically relevant to the U. S. Air Force, e.g., for determining risks encountered by planes staying on route for a known length of time. However, the Army, plant ecologists, and probably geographers in general will mostly be concerned with items that are exposed to the elements constantly. Any of these may be affected by given temperature values if the latter persist long enough at any time during the month. Therefore, conditional levels were considered more appropriate here.

The longest t-d refers to extreme occurrences, but extreme in <u>length</u> only, and not necessarily in temperature as well. Considering the variety of problems for which t-d data could be useful, it is clear that not only extreme temperatures could be critical, especially when persisting long enough. Evidently a temperature that is considered moderate in a given station could well be critical for a particular problem. Therefore, the longest t-d's have been treated here not for extreme temperatures only, but in fact for any temperature on one side of the monthly mean in each station. For durations <u>above</u> given levels the <u>upper</u> half of the local temperature range was covered, and for durations <u>below</u> given levels the lower half was covered. Durations for the remaining part of the range (e.g., the longest t-d above a <u>low</u> temperature) seem to be of secondary importance, and as their prediction would be subject to extremely high variability anyway, it was not attempted here.

The fact that only the longest t-d in a month, rather than all durations, has been treated here is suited to the need for information on critical t-d conditions. By concentrating on the extreme t-d's in a month only, the probability that any t-d relevant to a particular problem is exceeded can be more accurately ascertained than if all other durations were included as well.

Seasonal phenomena at any particular place could very well be affected by long durations of both high and low temperatures in the same month. Consequently, durations both above and below given levels seem to be of interest in each part of the year. In a comprehensive study of t-d's, both variables should therefore be treated for each season. In the present study, treatment was limited at this stage to durations "above" given values in July only, and durations "below" in January only. In practical application these seem to be of most importance, but it is realized that in case it is found that the distribution of t-d's can be effectively described, the scope should be widened as indicated above.

3. Data and Techniques

The source for all hourly temperature data is the "Local Climatological Data (Supplement)" published monthly by the U.S. Weather Bureau for individual stations. Hourly temperature records have been published from about 1950 until 1964, after which their publication was discontinued. Twenty-five stations from North America and the Pacific Ocean were treated in the present study. Not all of them could be included in each stage of the investigation. Data from ten more stations taken from Westbrook (1968) were treated in preliminary exercises.

The data on the t-d's in an individual station can be derived from the hourly temperature records by a relatively simple computer program (see Table I). The essentials of the procedure in regard to each station are as follows: The complete record of hourly temperatures is read-in and stored. Then for each predetermined temperature level, all hourly data for each month are scanned systematically. Whenever the specified temperature is encountered, a counter for the duration-length is set off, which will eventually retain the final length of each duration in a single month. These durations can then either be printed out or, otherwise, suppressed and only the longest

TABLE I. Program for obtaining durations at or above given temperature levels from hourly temperature records.

```
FORTRAN IV G LEVEL 1, MOD 1            MAIN            DATE = 69114          07/56/30            PAGE 0001

      C     PROGRAM 2
            INTEGER*2 LHT(31,31,24),N(1000)
            COMMON MDAY,NST(16),N,NY(64),ND(31),LHT,NMAX,LL,K,MM,NN
         20 FORMAT (I2)
            READ(5,20) MDAY                          ← # of day in month
            DO800 NN=1,16
         90 FORMAT (I3)
        800 READ(5,90) NST(NN)                       ← temp levels (here 60, 62, .., 90°F)
            DO900 NN=1,16
         13 FORMAT (I14///)
            WRITE(6,13) NST(NN)
            DO100 MM=34,64                           ← 1934 - 1964
            DO200 K=1,100                            ← counter of durations in one individual month
        200 N(K)=0
            MM=MM-33
            IF(MM.EQ.1) CALL INPUT
            CALL COMPT
            CALL OUTPUT
            MM=MM+33
        100 CONTINUE
        900 CONTINUE
            STOP
            END

            SUBROUTINE INPUT
            INTEGER*2 LHT(31,31,24),N(1000)
            COMMON MDAY,NST(16),N,NY(64),ND(31),LHT,NMAX,LL,K,MM,NN
            DO300 LL=1,MDAY
         40 FORMAT (2X,3I2,24I3)
        300 READ(5,40) NY(MM),M,ND(LL),(LHT(MM,LL,J),J=1,24)
            RETURN
            END

            SUBROUTINE COMPT
            INTEGER*2 LHT(31,31,24),N(1000)
            COMMON MDAY,NST(16),N,NY(64),ND(31),LHT,NMAX,LL,K,MM,NN
            K=0
            DO400 LL=1,MDAY
            DO500 J=1,24
            IF((J.EQ.1).AND.(LL.EQ.1).AND.(LHT(MM,1,1).GE.NST(NN))) GO TO 21
            IF((J.EQ.1).AND.(LL.EQ.1).AND.(LHT(MM,1,1).LT.NST(NN))) GO TO 500
            IF((J.EQ.1).AND.(LHT(MM,LL,1).LT.NST(NN))) GO TO 500
            IF((J.EQ.1).AND.(LHT(MM,LL,1).GE.NST(NN)).AND.(LHT(MM,LL-1,24).GE.
           1NST(NN))) GO TO 22
            IF((J.EQ.1).AND.(LHT(MM,LL,1).GE.NST(NN)).AND.(LHT(MM,LL-1,24).LT.
           1NST(NN))) GO TO 21
            IF((LHT(MM,LL,J)).LT.NST(NN)) GO TO 500
            IF((LHT(MM,LL,J-1)).GE.NST(NN)) GO TO 22
         21 K=K+1
         22 N(K)=N(K)+1
        500 CONTINUE
        400 CONTINUE
            NMAX=N(1)
            DO600 JJ=1,K
            IF(N(JJ).LT.NMAX) GO TO 600
            NMAX=N(JJ)
        600 CONTINUE
            RETURN
            END

            SUBROUTINE OUTPUT
            INTEGER*2 LHT(31,31,24),N(1000)
            COMMON MDAY,NST(16),N,NY(64),ND(31),LHT,NMAX,LL,K,MM,NN
         11 FORMAT (10(3X,2I5))
            WRITE(6,11) (JJ,N(JJ),JJ=1,K)
         12 FORMAT (I14///)
            WRITE(6,12) NMAX
            RETURN
            END
```

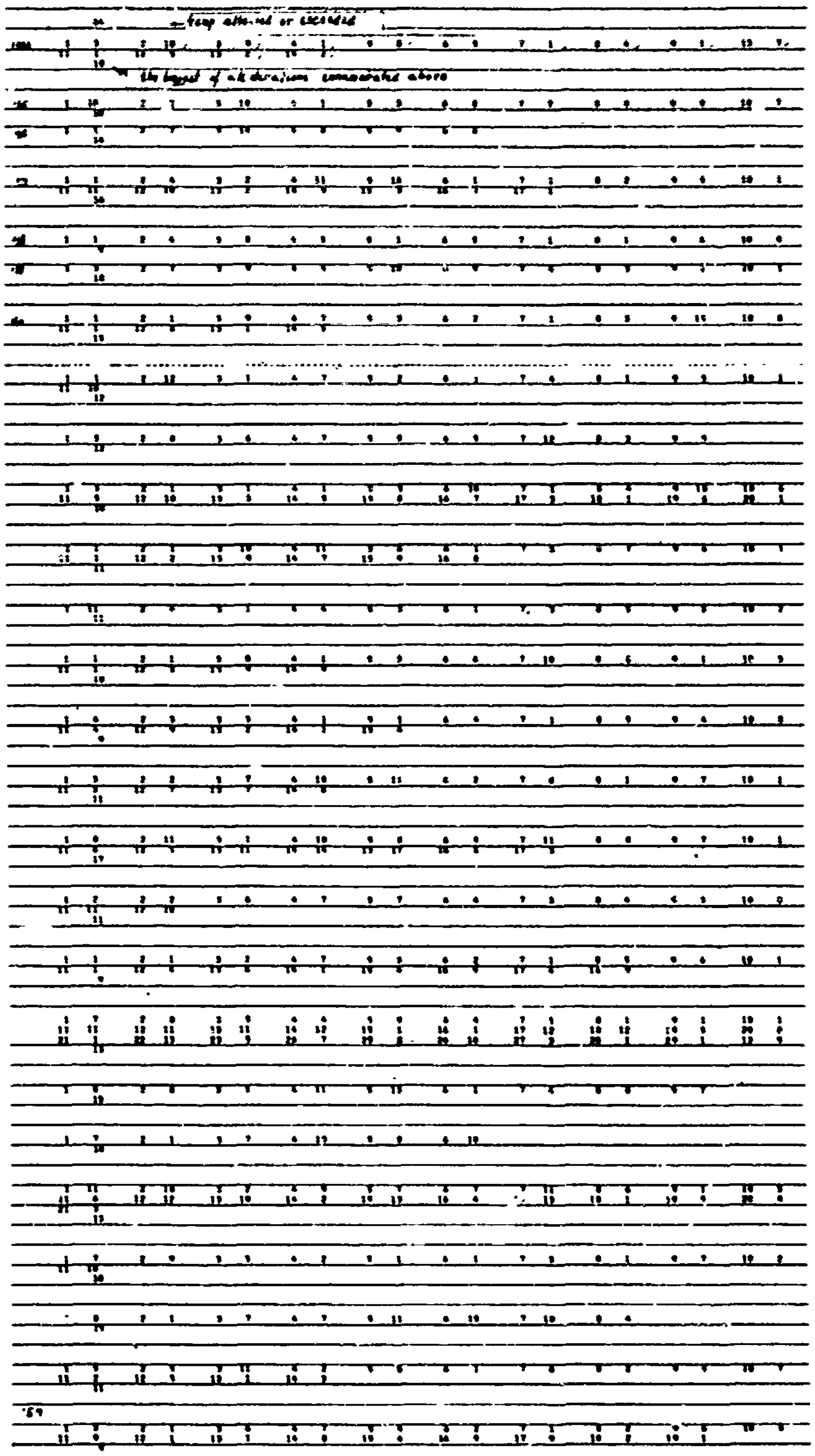
in that month printed out. This is done separately for each single month, after which the same procedure is repeated for each of the other temperature levels. A sample of the output sheets is presented in Table II, in which all durations for one month are first printed out, and then the longest of them printed out.

At the beginning of this investigation, much of the above procedure was done manually by Mrs. Westbrook.

A question may be raised as to whether the longest t-d values for a particular month in consecutive years constitute a random sample. This problem was not tested here, but it is adequately clarified by the following reasoning. Any two consecutive returns of a particular month (e.g., July) are eleven months apart. Except for long-range climatic trends, the existence of which is questionable, a relationship that would imply statistical dependence between values pertaining to consecutive return of a month seems improbable. Moreover, the longest t-d in a month is related to extreme weather occurrences producing cold or warm spells, which in most cases seem to be especially irregular.

For some stations, hourly temperature records were available only since 1953. Therefore, a 10-year record was uniformly used for all stations. The "smoothness" of the frequency distributions which were eventually obtained from these data (see Section 8) indicated that that number of years was adequate, at least in regard to the July variable. For the other one, i.e., t-d's "below" in the winter, more data would be helpful, but the few more years that might have been available for some of the stations would hardly make a difference. Reference is also made to the fact discussed in the following, that model distributions were not established on the basis of single stations.

TABLE II. A sample output sheet of temperature durations in July for one temperature level.



The adequacy of a 10-year record could be tested for one particular station (Boston, Mass.) in July. For this station a 31-year record (1934-1964) was made available by the USWB office in Boston, and was used also for checking the representativeness of the data for 1951-1960. The comparison of the distribution for the two periods is presented in Table III. The variable used is the longest t-d in a month above given levels. The distribution of the longest duration in both sets of data is compared at ten percentile levels covering the whole distribution range. The table shows very high agreement between the two sets. The few departures that can be found hardly fall into any pattern, and it can be assumed that they would be largely canceled out when being pooled with data from other stations.

No single distribution was originally expected to apply to all the stations in the world, or even most of them. The final model, if achieved, was to consist of a number of distributions, each representing one type of station. For the purpose of establishing a model distribution that applies to more than a single station, the t-d data from a number of stations were pooled together. This was done for a fixed month only (i.e., July) and so far as possible only for such stations that fell into climatologically definable groups and that had similar t-d distribution patterns (see Section 6). When the pooling was justified accordingly, it automatically made up for the relatively small amount of data available for individual stations, by making an enlarged data body available for establishing one type of a distribution. A distribution thus derived is therefore an average one for 10 returns of the same month in each of the stations included and is regarded here as an estimate of a model distribution of the longest t-d in the same type of station. The precision of that estimate is higher, the more data there are available for it, because

Table III. The distribution of the longest duration at or above given temperature in July, Boston, Mass., based on records of different length: (a) 1934-1964, (b) 1951-1960 (adapted from Table I, Chang, 1968).

Cum. rel. freq.		TEMPERATURE (°F)							
		64	68	72	76	80	84	88	90
	a	121	60	22	15	11	9	4	2
.10	b	121	65	21	14	11	9	3	2
	a	159	66	38	16	12	9	5	3
.20	b	141	66	39	17	12	9	4	3
	a	172	75	39	17	13	10	6	4
.30	b	179	71	40	17	14	10	6	4
	a	185	90	43	19	14	10	7	5
.40	b	185	79	44	19	14	10	6	4
	a	187	98	52	19	14	11	8	5
.50	b	188	96	45	19	15	10	8	5
	a	215	116	62	21	15	11	9	7
.60	b	257	113	58	23	18	11	8	7
	a	275	138	66	27	18	13	10	7
.70	b	333	114	60	27	18	13	10	7
	a	382	141	70	36	18	13	10	8
.80	b	353	137	70	29	18	13	10	8
	a	353	165	92	44	20	15	10	8
.90	b	376	141	92	44	18	13	10	8
	a	477	233	158	92	22	17	12	10
1.00	b	473	233	101	48	19	15	10	9
ave-	a	234	112	59	28	15	11	7.5	5.5
rage	b	260	111	57	26	16	11	7.5	5.7
Std.	a	96	45	30	19	3.3	2.3	2.6	2.5
dev.	b	111	48	24	11	2.7	2.0	2.5	2.3

this reduces the variability (error) of the estimate, which in this case is a distribution. On the other hand, the amount of data available for one distribution may be limited by the number of stations having similar distribution patterns.

The error mentioned above refers to the variability of the distribution itself, i.e., each of its individual features such as its average, percentile points, etc. It should not be confused with the variability within the distribution as a whole, which is, in fact, the scatter of a variable that has this distribution. The latter refers to the "width" of a distribution.

A distribution thus derived will be used to make predictions of the longest duration in a month above (or below, as the case may be) a given temperature in a station to which the distribution applies. Predictions will have the form of a numerical range of durations for which a given temperature can be expected to last at specified probability levels. These could be either confidence limits, bounded on both sides, or one-sided ranges corresponding to given levels of risk.

The accuracy of estimated ranges may be viewed from two different aspects. One is directly linked to the preciseness with which the distribution, obtained from samples, represents the true (model) distribution. This aspect of accuracy can hardly be tested in our case, but when a considerable number of stations of one type is available for obtaining one distribution, the accuracy will be at least as high as that of most estimates used widely in climatology.

Another aspect of the "accuracy" of a range may refer to its width. Obviously, a predicted range of 5-7 hours at a given probability level is more valuable than another one of 0-3 hours. Although one could figure the expected event more "exactly" from the first range, it could nevertheless not be regarded as more accurate. The larger range may be reflecting

actual conditions in a certain station in which weather patterns are more irregular. In this case the wider range is a true reflection of reality, and not a weakness of the prediction model.

The components of the variance in a pooled distribution were used in this study to evaluate the effectiveness of temperature standardizations (Section 5) and the appropriateness of station-grouping (Section 6). The components were determined in an analysis of variance done separately for fixed temperature levels. The variance of the duration (for one fixed level) <u>within</u> stations reflects the natural variability of t-d's (this is referred to hereafter as the variability "within" stations). It is essentially irreducible and is hardly affected by any manipulation of the data. On the other hand, the variance between stations represents the amount of variance added in the process of pooling data from different stations. This component is largely reduced by effective methods of temperature standardization and by appropriate grouping. Therefore, it can serve in evaluating the effect of these manipulations. Further remarks on the use of the analysis are made in the concluding paragraph of Section 4.

4. <u>The Statistical Distribution of t-d's in Two Special Cases</u>.

Some attempts were made to determine the shape of the distribution of the longest t-d's within temperature levels, such as those shown on the tables in the Appendix. Such attempts were restricted by the fact that the available data were insufficient for proper curve fitting. Obviously, the distribution of t-d's can be considered only within one temperature level at a time, because the expected values vary among different levels. The same must be assumed also in regard to t-d's at different stations. Thus, only 10 values could be available for each individual distribution. This difficulty

was overcome in two cases in each of which the distribution of the longest t-d within temperature levels was found to be normal, or at least very close to normal.

One instance concerns July t-d's "above" in Boston, for which 31 values were available in each level, as mentioned previously (Section 3). Durations at 16 temperature levels (2° apart) were tested (Chang 1968). It should be noted that these 16 tests, though separate, are not mutually independent, but the extent of dependence apparently decreases sharply for levels more widely apart. Results of the tests are presented in Table IV.

Two tests were independently applied. The first one was a chi-square test. As the usually accepted formal requirement concerning the number of items, i.e., N=50, could not be fully satisfied, the exact value of the critical significance levels should probably not be taken exactly to the last decimal. However, in most cases, these levels were so high as to justify an unambiguous statistical conclusion.

A Kolmogorov-Smirnov test was also independently applied to the same data. For this test there is no required sample size. It is also considerably more powerful because each individual observation is considered. However, a slight imperfection may still be involved here, as the "expected" normal distribution was specified by using only estimates for its parameters, i.e., the distribution was not fully specified. Here again the correct probability pertaining to the results of each test may be a little lower than shown, but as in the former case, most probabilities are high enough to warrant the correctness of the conclusions inferred from them.

The results indicate that except for 2 of the 16 temperature levels, 76°F and 78°F, departures from normality are insignificant. The significance of the two levels mentioned is affected by unusual occurrences in two of the 31 years,

TABLE IV. Test of goodness of fit of the longest temperature duration in July, Boston, Mass., to the normal distribution. t_m is temperature on R_m scale, D_{max} is the maximum departure in a Kolmogorov-Smirnov test, and a is the highest significance level at which result is insignificant; N = 31.

°F	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90
t_m	.07	.12	.18	.23	.28	.34	.39	.44	.50	.55	.60	.66	.71	.76	.82	.87
χ^2	.96	3.8	2.0	2.1	1.0	1.9	1.5	2.0	6.8	5.4	3.2	2.2	2.5	0.3	1.3	0.8
d.f	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1
a	.60	.18	.15	.15	.32	.17	.22	.15	.01	.02	.08	.14		.60	.25	.40
D_{max}	.13		.207		.116		.16	.183	.27	.307	.20		.19		.149	.134
a	.25+		.15		.25		.25+	.25	.025	.005	.15		.20		.25+	.25+

when the specified temperature persisted for about 90 hours (1949 and 1963), as compared to the third highest duration of 48 hours only, and the average of 25 hours. On the whole, there is a very strong indication that the longest t-d above given levels is normally distributed.

Besides the test using Boston data, the distribution of the longest t-d in July was tested also with another set of values. This one comprised t-d's from 4 stations taken together, thus making 40 items available for tests within each temperature level. Pooling t-d data from different stations is made technically possible by having the original temperature values reduced to a common basis, by a process of standardization discussed in Section 5. Although the four stations chosen are quite different in certain respects, their respective t-d distributions have practically the same pattern. This is shown in Table V, by a comparison of the averages and the variability for all stations. The comparison is made within each temperature level, t_m, the exact meaning of which is brought out in a later section.

A chi-square test was then applied to the distributions within 9 temperature levels. These covered the whole upper half of the temperature range, outside the upper tail where the distribution becomes truncated. The results are shown in Table VI, which clearly indicates that this distribution can also be regarded as normal.

Obviously, the results obtained here apply only to the stations and duration ranges specified. No direct analysis has been made of other data, but some essential features common to t-d distributions in general are brought out in Section 8 of this report. It has been found that distributions are somewhat distorted in those parts that correspond to durations a little longer than 24, 48, or 72 hours.

TABLE V. The distribution of the longest duration at or above temperature levels (given on R_m-scale) at four stations, 1951-1960.

10-YR MEAN AND STANDARD DEVIATION OF LONGEST T-D, IN HOURS
(DURATION AT OR ABOVE GIVEN VALUES IN JULY, R_m STANDARDIZATION)

STATION	TEMPERATURE LEVEL .55	.60	.65	.70	.75	.80	.85	.90	.95	1.00
PHOENIX	15.8	14.0	12.0	10.7	9.5	8.0	6.6	5.1	3.3	1.3
ST DEV	1.89	1.68	1.56	1.92	1.23	1.44	1.91	2.09	2.24	2.14
DENVER	15.4	14.2	12.9	11.6	10.8	9.3	7.5	5.2	2.3	1.0
ST DEV	1.54	1.27	.90	1.27	1.62	1.48	1.65	2.65	2.46	2.10
SPOKANE	16.9	15.2	13.2	12.0	10.7	8.8	8.2	5.9	4.3	1.4
ST DEV	1.85	1.97	1.18	1.44	1.17	1.23	1.55	2.77	2.88	2.10
YUMA	16.3	13.6	12.1	10.5	9.0	8.2	6.8	5.3	2.6	1.2
ST DEV	1.95	1.49	1.08	1.15	1.35	.98	1.22	2.06	2.41	1.99

ANALYSIS OF VARIATION OF T-D FOR STATIONS INCLUDED IN TABLE ABOVE
(DURATION AT OR ABOVE GIVEN VALUES IN JULY, R_m STANDARDIZATION)

TEMP LEVEL	MEAN DURATION	S(B)	S(W)	S (TOTAL)	F(3,36)
.55	16.10	2.04	1.91	1.92	1.14
.60	14.25	2.15	1.71	1.75	1.57
.65	12.55	1.87	1.27	1.32	2.15
.70	11.20	2.26	1.55	1.62	2.11
.75	10.00	2.81	1.42	1.58	3.88
.80	8.57	1.86	1.37	1.41	1.85
.85	7.27	2.30	1.69	1.74	1.84
.90	5.37	1.13	2.54	2.46	.19
.95	3.12	2.80	2.64	2.66	1.12
1.00	1.22	.54	2.19	2.11	.06

Table VI. Test of goodness of fit of the pooled distribution of longest duration in July at four stations to the normal distribution (see text for details on stations and temperature reduction).

Temp. level (t_m)	.55	.60	.65	.70	.75	.80	.85	.90	.95
Chi-square	2.45	2.25	1.64	2.24	1.62	2.60	1.65	5.90	5.47
Deg. of freedom	4	3	1	3	2	2	3	5	4
a*	.60	.50	.20	.50	.40	.25	.60	.30	.20

*a = highest significance level at which not significant.

The above remarks have been made here in connection with the analysis of variance that has been employed for certain purposes in the following sections. As normality could not be assumed, no strict F-tests were formally carried out on the components of the total variances that were obtained. The analysis was used here merely to obtain estimates of the two components of the variability in pooled sets of t-d data. For that alone, no assumptions concerning the distribution have to be made.

5. Temperature Standardization

A major problem in this study concerns the pattern of the frequency distribution of the longest t-d. If a model of some generality is to be suggested, the question immediately arises as to the extent to which the distributional patterns are similar for different stations. To have such patterns brought out

more clearly and to compare them for different stations, the distributions need to be abstracted from some of the characteristics of the specific station to which they apply. In our case, the specific characteristics to be eliminated from the individual distributions could include the general temperature level at a station, the amplitude of temperature changes, the frequency distribution of hourly temperatures, and perhaps some others. Such abstractions can be made in a way that is similar to the standardization of a variable in statistics, i.e., the employment of some transformation function to standardize an independent variable. In our case the variable to be transformed would be hourly temperature, and the purpose of this, in technical terms, is to bring the t-d distributions for different stations as close as possible to each other.

Four standardization transformations have been attempted here and their efficiency tested: (1) In the R-standardization, temperatures t in any one station are reduced to values t_a in the range of 0 to 1.00 by using the absolute minimum temperature ever observed at that station in that month (T_{min}) and the absolute range (R) between that and the absolute maximum temperature:

$$t_a = \frac{t - T_{min}}{R}$$

Thus actual temperatures, as measured from their absolute minimum, are reduced by this transformation into proportions of the absolute temperature range R of the same station. For example, the absolute maximum temperature in any station will have the uniform value of t_a=1.00. This standardization has been employed by Westbrook (1962) and later also by Hook (1964 and 1966). It is based on the assumption that the longest t-d in any one station is related to the extreme temperature

occurring there, which is probably true for the shortest durations (i.e., the most extreme temperatures). Extremes for 25 years were used as recommended by Hook (1966, p. 3).

(2) <u>The R_m standardization</u> is similar to the previous one, but it employs the average monthly extremes, $\bar{t}_{min}$ and $\bar{R}_m$, instead of the long-term absolute extremes, T_{min} and R.

$$t_m = \frac{t - \bar{t}_{min}}{\bar{R}_m}$$

Thirty-year averages were used for $\bar{t}_{min}$ and $\bar{R}_m$. In this standardization, the actual temperatures are expressed as a proportion of the average monthly temperature range $\bar{R}_m$, above the average monthly minimum. The parameters used in this standardization are more stable ones, which consequently is also true of the transformed values of temperature obtained.

(3) In the <u>G-standardization</u>, the average monthly frequency distribution of the hourly temperatures is used. Using this standardization, an actual temperature is expressed in terms of the cumulative relative frequency of that temperature in the monthly distribution. For example, for a station at which a temperature of 5° or less is encountered in 15% of all hourly observations in the same month, the temperature of 5° will be transformed into 0.15. The absolute extremes will be 0.00 and 1.00 as in the R standardization, but in between these limits the actual frequency distribution of temperature levels is used rather than an assumed uniform distribution.

This transformation was similarly used by Gringorten (1966), though for a different purpose. The required frequency distributions for 1951-1960 were obtained from the U.S. Weather Bureau's "Decennial Census of United States Climate - Summary of Hourly Observations," published separately for most Weather Bureau stations.

(4) The W-standardization was suggested by Wadsworth in 1967. It employs the average monthly temperature $\bar{t}$ and its standard deviation S, obtained from the hourly observations:

$$t_s = \frac{t - \bar{t}}{S}$$

Thus temperatures are expressed in terms of the standard deviation of all hourly records for that month, measured from their average. The average monthly temperature becomes 0.0 and the highest ones come close to 3.0. In standardizing temperatures in station groups, in which all stations have the same distribution except for the values of the mean and the standard deviation, this standardization would give identical results to that designated G. For instance, this would be true if all these distributions were normal. Actually, however, this is an improbable situation. To obtain the values for the average and the standard deviations, the same source as for the G-transformation was used.

An R_d - transformation, using average daily extremes similarly to Numbers 1 and 2 above, was also attempted, but was given up soon for lack of promising result.

The effect of standardizing actual temperatures on t-d statistics is illustrated in Figure 1. Temperature ranges for five stations are shown, all with different temperature means and ranges. Durations are also shown f three fixed t_m values at each station: 1.0, 0.8, and 0.6. The actual temperature corresponding to each of these values can be ascertained from the adjacent temperature scale (on the left of Figure 1). Ob ously, if durations above a fixed temperature value (say above 90°F) were examined, then the corresponding durations would differ widely among the stations. At Phoenix, the longest t-d at or above 90° in July averages about 18 hours;

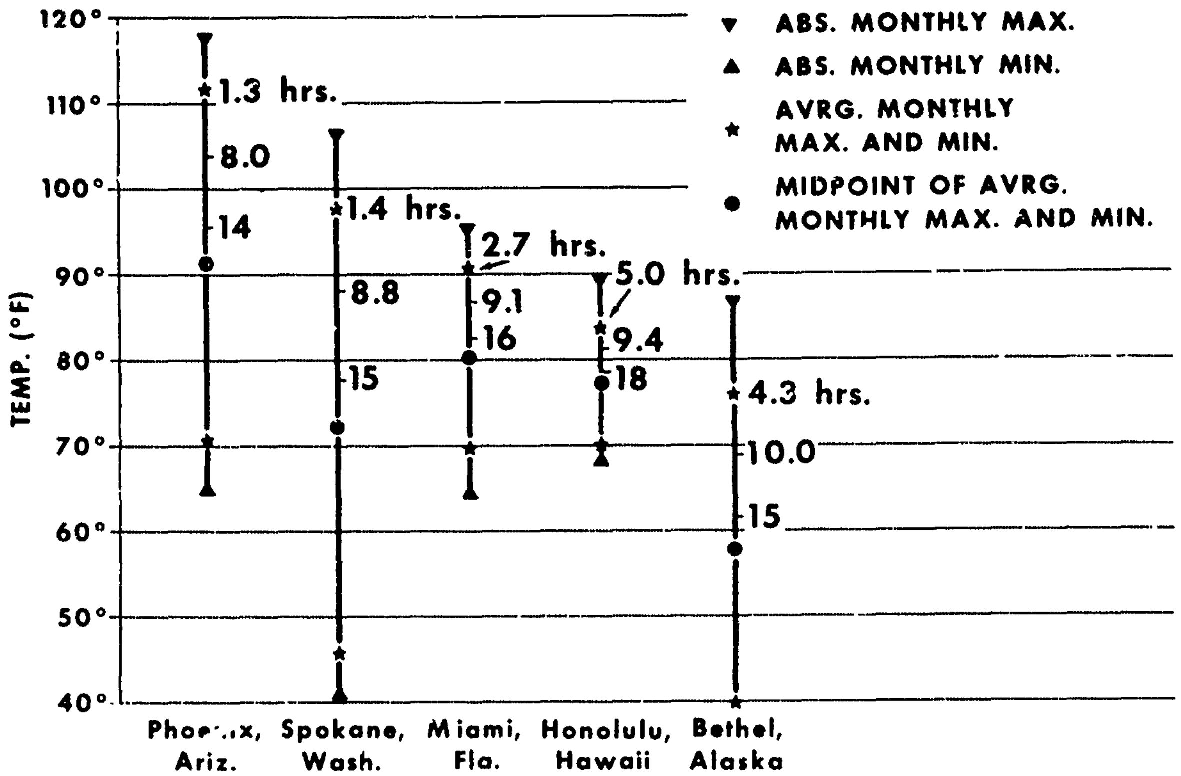


Figure 1. Illustration of the R_m-temperature-standardization. Averages of the longest duration in July at or above temperature levels given both in degrees and in terms of the R_m standardization. The three duration values given for each station uniformly refer to values of 1.00, 0.80, and 0.60 on the R_m-scale, respectively.

at Miami it is 2.7 hours; and at Bethel it is never even attained. However, turning to the durations corresponding to a fixed standardized value, the differences between the stations become very small. Thus, for a standardized temperature of 0.8 (second value shown for each station), the durations at the same stations are 8.0, 9.1, and 10.0 hours, respectively, which are very close to each other.

Technically, standardizing the temperature values lends to t-d distributions from different stations a more uniform pattern than is attainable without their use (see Fig. 2). The ideal situation would, of course, be to find a transformation that would eliminate all differences among stations. Referring to Figure 2, this would mean the practical coincidence of the curves for all five stations shown. Clearly, this is not effected for these particular stations by any of the standardizations, but some come closer to that goal than others.

The effectiveness of the standardizations suggested above was compared with respect to their effect on the uniformity of the patterns of t-d distributions among the stations studied. With an ideal standardization the patterns should be freed from all peculiarities of the individual stations. Consequently, t-d distributions in all of them would coincide. As an indicator of the extent to which this was effected by each of the standardizations, the variance among the duration patterns in the individual stations was used.

The variance "between" station averages was arrived at through separate analyses of variance for all individual durations corresponding to each single temperature level. An example of the numerical results of the analysis for all four standardizations is presented in Table VII.

The results were also plotted on a continuous basis in Figures 3 and 4. To compare the results for all four standardizations, those obtained for temperature levels expressed in

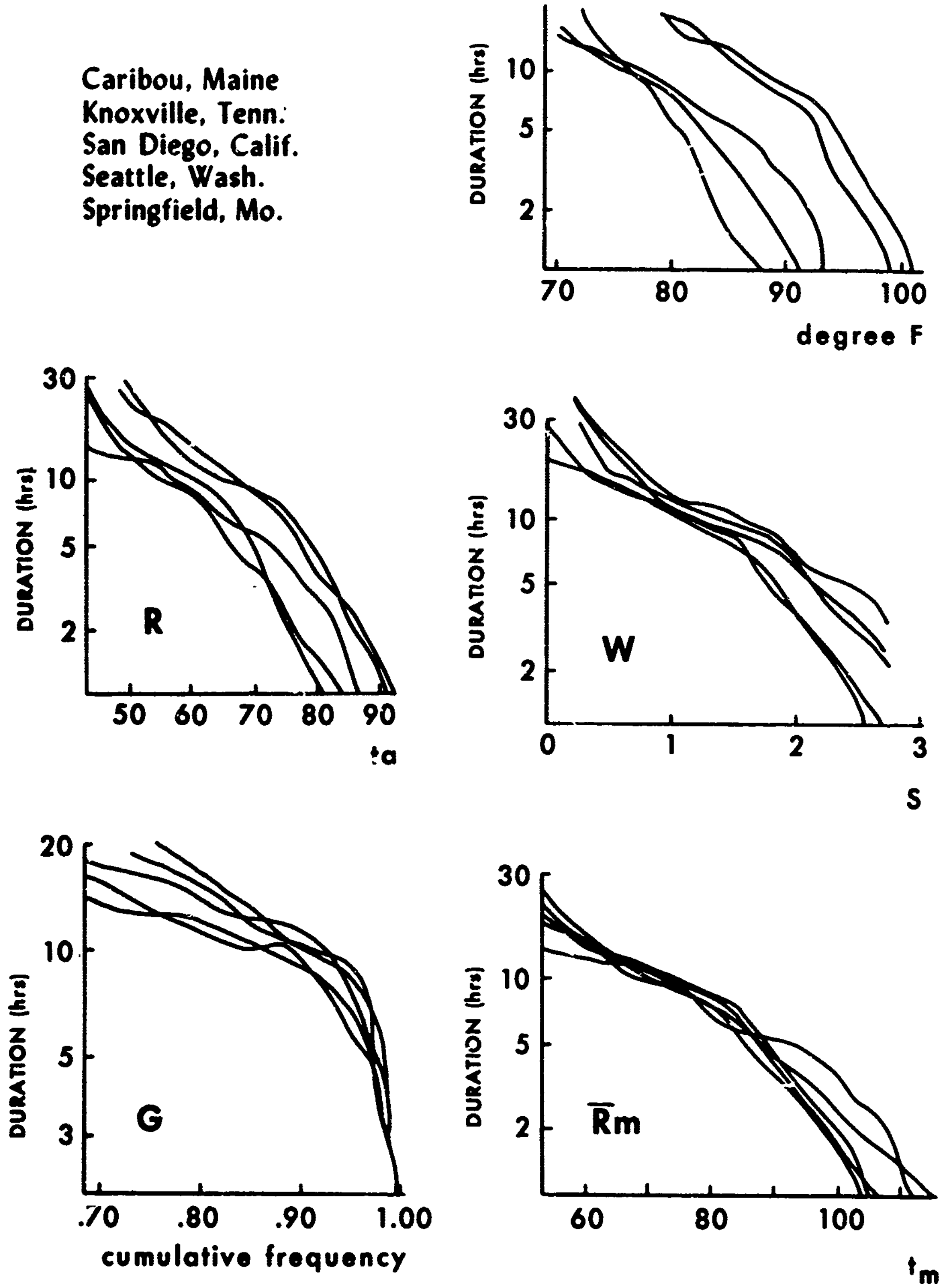


Figure 2. Illustration of the effect of temperature-standardizations: The average longest temperature-duration in July in 5 stations, plotted on various temperature scales. The characters R, W, G, R_m refer to transformed temperature scales described in the text.

Table VII Analysis of variance of the longest duration at or below given temperature levels in January, in pooled distribution models (19 stations) based on different temperature standardizations. The results of the analysis for each temperature level are contained in one line. F-Values should be interpreted in terms of statistical significance.

ANL OF VAR OF T-D FOR STATIONS INCL-D IN TABLE ABOVE

DURON AT OR BELOW GIVEN VALUES IN JANUARY, R STDZON

TEMP LEVEL	MEAN DUR-N	S(B)	S(W)	S (TOTL)	F(17,162)
0.55	100.39	[illegible]	66.85	77.80	4.73
0.50	76.13	[illegible]	50.12	59.13	5.12
0.45	51.11	89.15	34.42	42.89	6.63
0.40	33.87	57.59	26.12	30.53	4.86
0.35	23.33	36.31	20.64	22.60	3.89
0.30	15.32	22.09	15.10	15.98	2.14
0.25	9.61	11.19	11.38	11.36	0.97
0.20	5.22	8.97	8.39	8.45	1.14
0.15	2.36	5.65	5.12	5.17	1.22
0.10	0.91	3.36	2.63	2.71	1.63

ANL OF VAR OF T-D FOR STATIONS INCL-D IN TABLE ABOVE

DURON AT OR BELOW GIVEN VALUES IN JANUARY, SM STDZON

TEMP LEVEL	MEAN DUR-N	S(B)	S(W)	S (TOTL)	F(18,171)
0.35	46.03	90.20	38.31	[illegible]	6.71
0.30	35.60	73.96	29.89	[illegible]	6.12
0.25	26.84	55.41	25.30	29.52	4.80
0.20	20.93	39.86	21.75	24.07	3.36
0.15	15.71	29.64	17.40	18.90	2.87
0.10	10.93	17.65	13.76	14.10	1.65
0.05	7.04	13.49	10.95	10.69	1.73
0.	4.63	10.75	8.27	8.54	1.69
-0.05	2.84	8.57	6.33	6.50	1.83
-0.10	1.42	5.20	3.75	3.91	1.93

ANL OF VAR OF T-D FOR STATIONS INCL-D IN TABLE ABOVE

DURON AT OR BELOW GIVEN VALUES IN JANUARY, W STDZON

TEMP LEVEL	MEAN DUR-N	S(B)	S(W)	S (TOTL)	F(18,171)
-0.25	76.19	148.03	51.34	66.87	8.31
-0.50	59.00	114.75	45.24	55.73	6.43
-0.75	47.40	108.13	40.33	49.26	6.16
-1.00	34.97	71.57	31.00	36.84	5.33
-1.25	25.03	45.36	24.70	27.41	3.35
-1.50	18.87	33.96	20.17	21.86	2.83
-1.75	13.13	21.29	14.85	15.58	2.06
-2.00	8.58	15.79	11.82	12.26	1.78
-2.25	5.25	11.98	8.97	9.29	1.79
-2.50	3.44	10.41	7.11	7.49	2.14

ANL OF VAR OF T-D FOR STATIONS INCL-D IN TABLE ABOVE

DURON AT OR BELOW GIVEN VALUES IN JANUARY, B STDZON

TEMP LEVEL	MEAN DUR-N	S(B)	S(W)	S (TOTL)	F(18,171)
-0.75	44.03	91.13	40.15	47.43	5.15
-1.00	32.64	63.81	30.38	34.97	4.41
-1.25	22.99	39.84	22.35	24.56	3.18
-1.50	17.51	30.98	18.49	20.07	2.81
-1.75	11.47	17.15	12.97	13.42	1.75
-2.00	7.68	18.93	10.87	10.87	1.81
-2.25	4.66	6.88	7.47	7.42	0.85
-2.50	3.07	5.48	6.03	5.98	0.83
-2.75	2.08	4.95	5.13	5.11	0.93
-3.00	1.52	4.69	4.57	4.58	1.05

BETHEL, ALASKA
BROWNSVILLE, TEX.
CARIBOU, MAINE
DAYTON, OHIO
DENVER, COLO.
HONOLULU, HAWAII
KNOXVILLE, TENN.
MIAMI, FLA.
MOBILE, ALA.
PHOENIX, ARIZ.
PONAPE, PAC. OC.
SALT LAKE CITY, UTAH
SAN DIEGO, CAL.
SAN FRANCISCO, CAL.
SAVANNAH, GA.
SEATTLE, WASH.
SPOKANE, WASH.
SPRINGFIELD, MO.
YUMA, ARIZ.

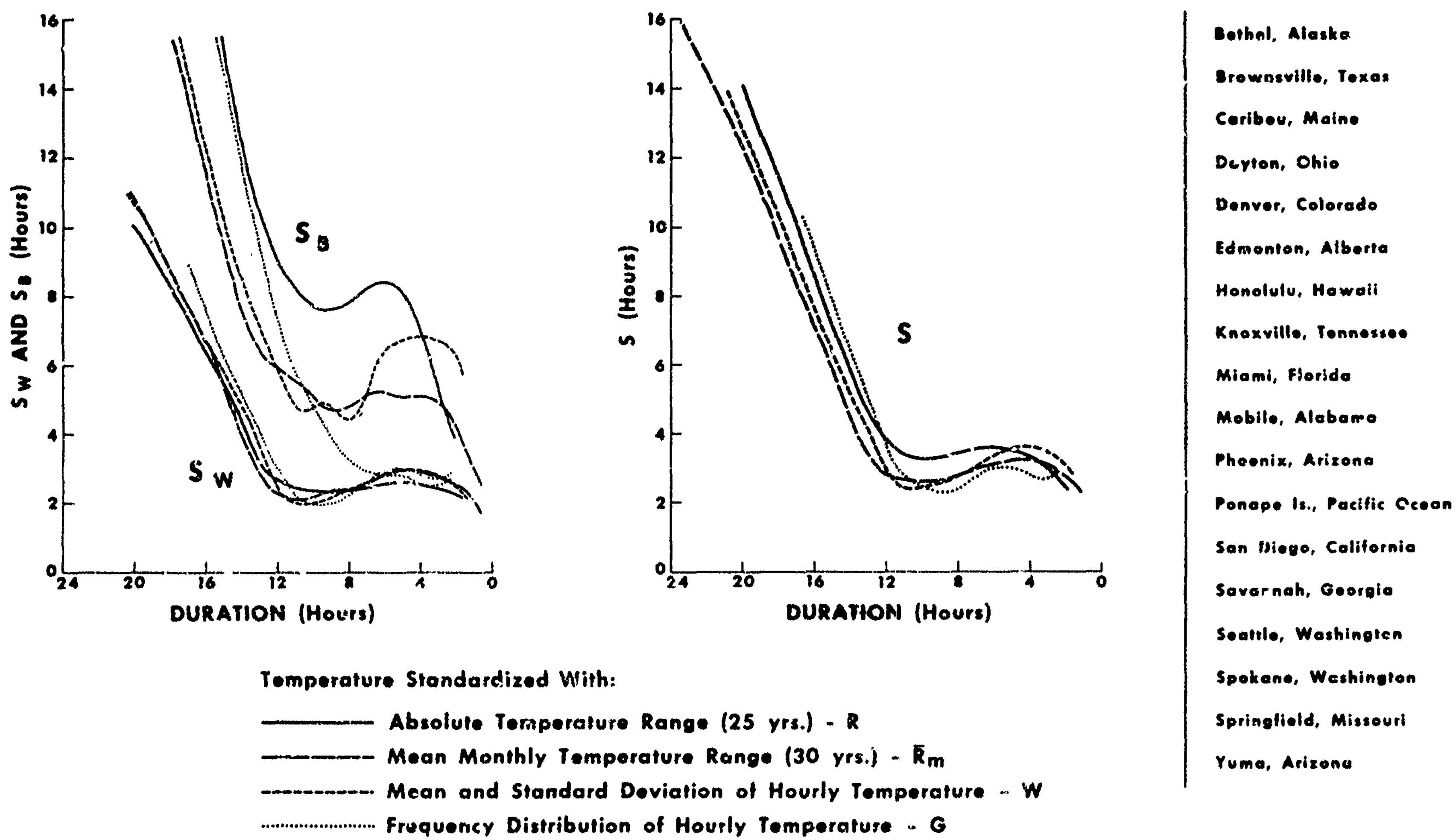


Figure 3. The variability of the longest durations at or above any temperature in July, in a pooled distribution model for 18 stations in North America. Temperature standardized separately on 4 different scales.

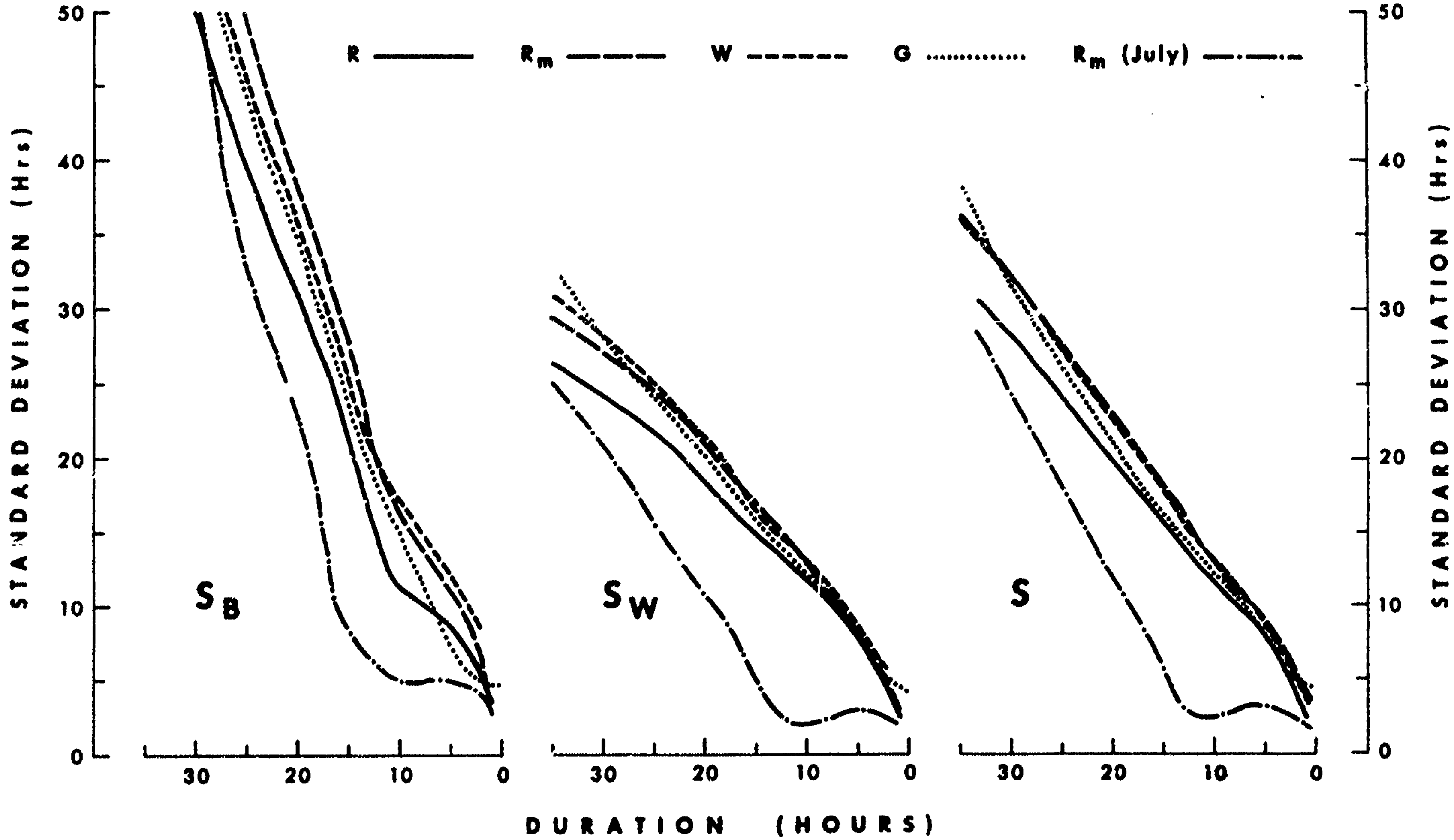


Figure 4. The variability of the longest duration at or below any temperature in January, in a pooled distribution model for 19 stations in North America (listed in Table VII). Temperature standardized separately on 4 different scales.

four different terms had to be plotted on a common basis. For this, the average duration corresponding to each level was used (see second column in Table VII and also Figures 3 and 4.)

The analysis of variance brings out two different aspects of the variability of t-d's for any fixed temperature level. As mentioned above, the effect of the temperature standardizations is best brought out by one of them, the variance "between" stations, S_b. (In effect, the square root of the variance is used all through this discussion.) However, we will not use it for that purpose, because it is the combined effect with the other component, S_w, in which we are ultimately interested. The variance "within" stations, S_w, is affected much less, of course. This component reflects better than the others the variability that is inherent in the t-d variable in nature. It represents the actual year-to-year variability of the longest t-d in a month observed for constant temperature level and constant climatic regime, i.e., at a single station. Obviously, this variability is a feature of the natural phenomenon itself (under constant conditions), and is irreducible by any manipulation (except effective weather control).

The effects of the two components are combined in the total variance, S. The latter reflects the variability in a pooled frequency distribution, obtained for a group of stations. It will be used to estimate the variability of the predictions that can be made when using that distribution as an estimate of a model distribution.

In terms of the total variance, S, in July, the R_m standardization appears to be preferable (Fig. 4). Differences between standardizations are not large altogether, but the variability for average durations of 5 to 15 hours is about 15-40% lower when using R_m rather than the R-standardization. Differences in relation to the other two standardizations are even smaller; consequently, the advantage offered by use of

any of them is definitely too small to justify the considerable practical complications involved in their use for standardizing temperature values.

For t-d's "below" in January, the situation is reversed, even though to a rather insignificant extent (Fig. 4). This probably indicates a stronger relationship of the longest duration of low temperatures to the extreme temperature than that of the longest durations of high ones. The variance of the t-d's "below" is altogether very high compared to that of the July variable, which makes the percentage differences among standardizations in January very small. Therefore, the potential improvement of a distribution model effected by using any particular standardization could only be small. Thus, there seemed to be no compelling reason for adopting a different standardization for the January variable than for the July variable, and R_m was uniformly employed throughout this study.

The choice of the R_m standardization was also supported by analyses done on data from smaller groups of stations. This includes stations that had been included in the above analysis and also 10 others that had not*. It was also found that when considering the t-d patterns, the stations lent themselves much better to stratification with the use of R_m than with any of the other standardizations, as explained in the next section.

In conclusion, it should be pointed out that even though differences among the suggested standardizations are small, the use of any of them greatly reduces the variability in a

* Barrow, Als.; Bismarck, N.D.; Boston, Mass.; Dallas, Tex.; Des Moines, Iowa; Fairbanks, Als.; Fresno, Calif.; San Juan, P.R.; Tatoosh Island, Wash.; Washington, D.C.

pooled distribution model, as compared to what it is on an unreduced temperature basis. G and W standardizations did not seem to offer any advantages. Use of either of them requires extensive information that is readily available for relatively few stations over the world. This would largely restrict the practical applicability of any model that could be achieved. Therefore, these standardizations are not recommended for use in t-d studies. The R_m standardization was chosen for use in this study, but its advantage over the R standardization is admittedly not very strong. In some respects, the latter would have been equally suitable.

6. Stratification of Stations

In the preceding section, an attempt to reduce the variability of the frequency distribution of the longest t-d in a rather diversified group of stations was discussed. Another way to achieve the same goal readily presents itself. It arises from the recognition of the possibility that the t-d distribution patterns may be more similar among themselves in groups of stations fitting into some climatic classification or other. A stratification of the stations was therefore attempted. Here again, the components of the variance were used for analyzing the effectiveness of any grouping.

Essentially, a stratification is intended to reduce S_b, the variance between samples (within strata). This is so in our case also, where samples are t-d data for individual stations. S_b is the only component of the variance that can be substantially affected by the grouping. Unfortunately, however, this component has little weight in determining the total variance because for standardized t-d data the variance "between" stations is, generally speaking, not much larger than "within" them. Consequently, the net effect of any stratification on the total scatter is limited.

Stratification of a group of over 20 stations was attempted, considering t-d distribution patterns of individual stations. Such attempts were made, using each temperature standardization separately. As the variability "within" stations is essentially irreducible, attention was focused on the variability "between" average t-d patterns at individual stations, some of which are shown in Figure 2. A separate attempt was also made to concentrate on stations at which the variance "within" is low.

Some interesting groupings emerged when using the R_m standardization on July t-d's, even though only one of them seemed to be of practical significance at this stage of the study. The only group of considerable size that clearly presented itself consisted of all the stations of pronounced continentality that had been included in the study, namely, Dayton, Ohio; Denver, Colo.; Edmonton, Alta. (Canada); Knoxville, Tenn.; Phoenix, Ariz.; Spokane, Wash.; Salt Lake City, Utah*; Springfield, Mo.; and Yuma, Ariz. (see group 1 in Figure 5). The effect of separating this group from the rest of the stations in establishing a pooled distribution model is brought out in Figure 6. It can be seen that although the reduction of S_b is outstanding, the overall effect is much less impressive: for temperatures higher than t_m 0.65, the overall scatter in the continental group amounts to 80-90% of the original, which is only a small improvement. It is probably not altogether insignificant (see Section 8), but it is definitely less than was expected by some experts** as well

* Data incomplete.

** Minutes of meeting of NAS-NRC Committee on Military Geography, Advisory Board on Military Personnel Supplies, US Army Natick Laboratories, 20-21 July 1966, p. 5.

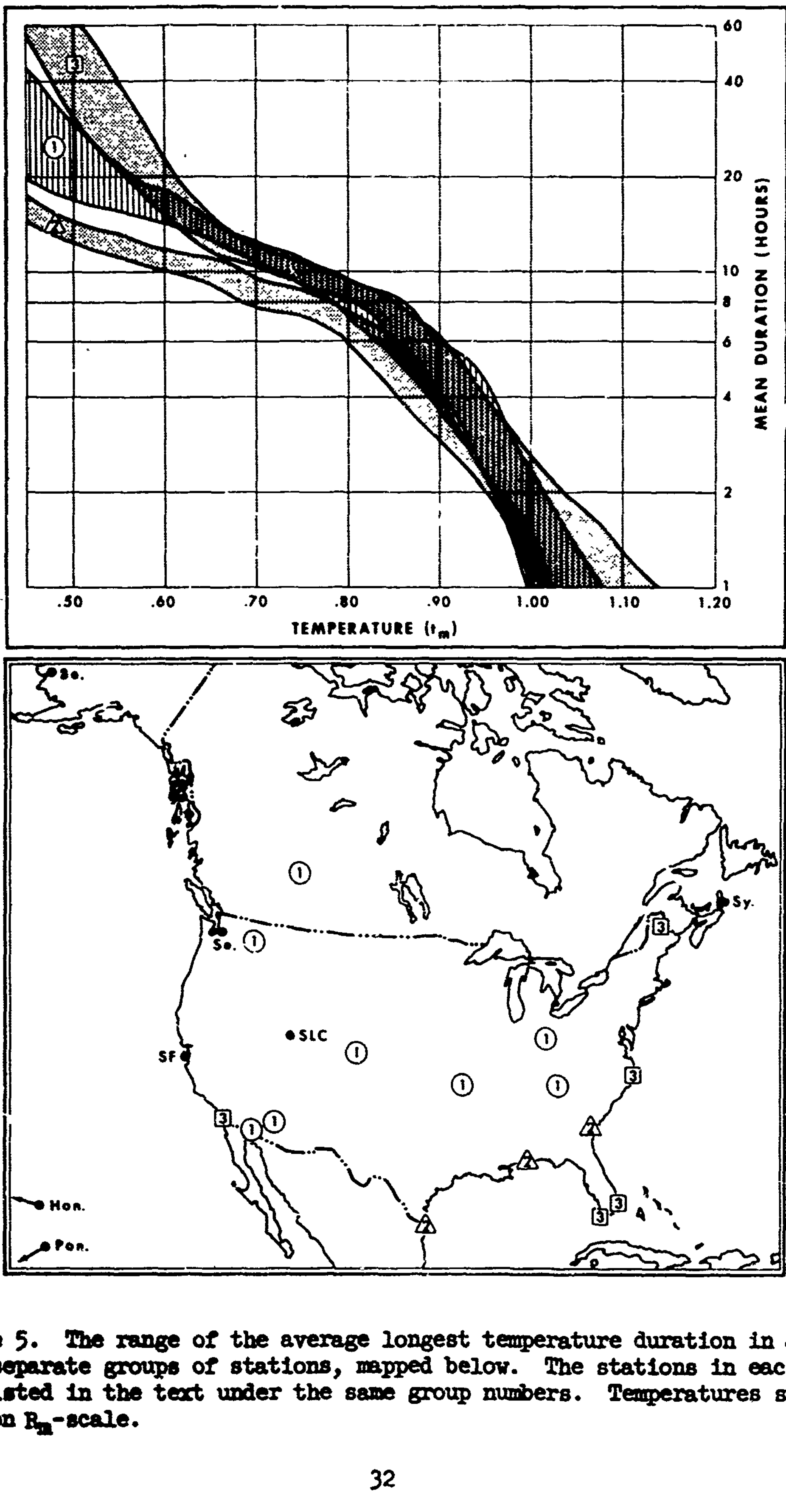


Figure 5. The range of the average longest temperature duration in July in 3 separate groups of stations, mapped below. The stations in each group are listed in the text under the same group numbers. Temperatures standardized on R_m-scale.

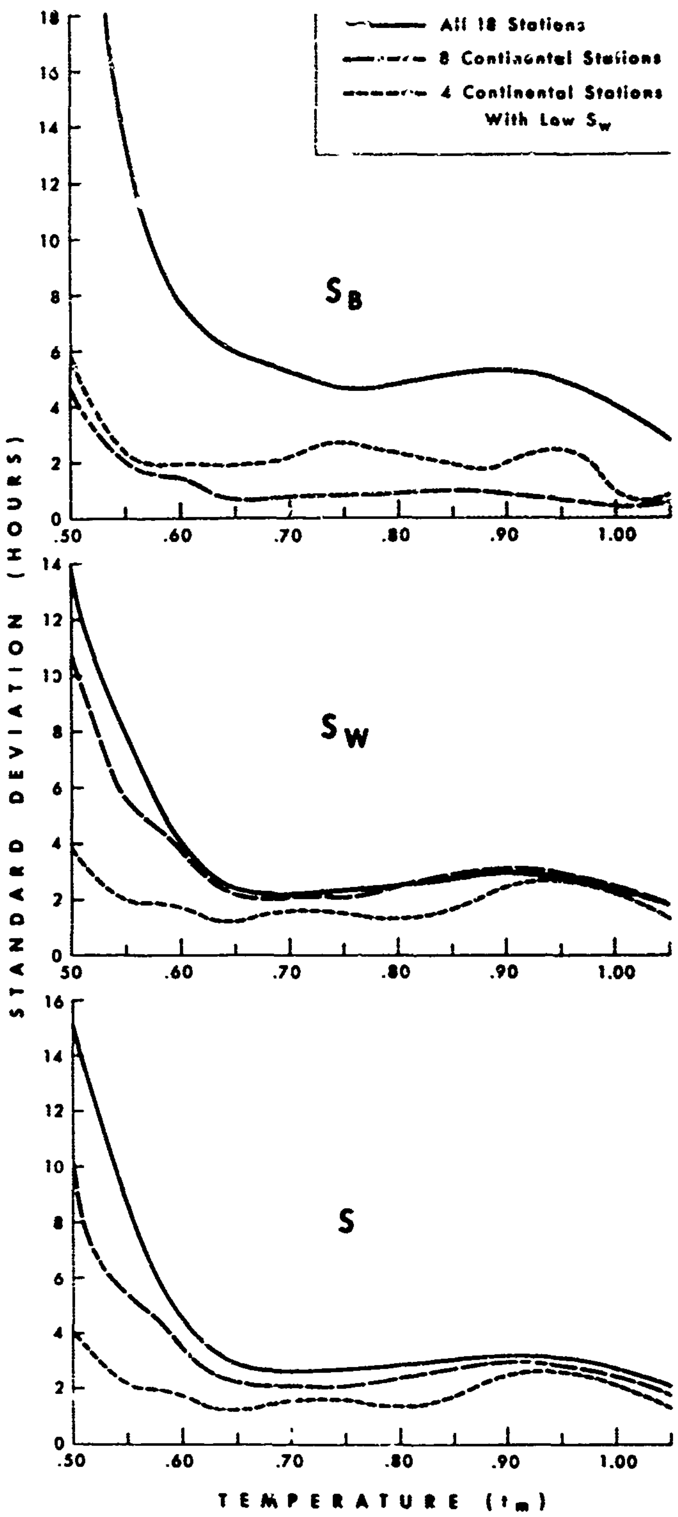


Figure 6. The variability of the longest duration at or above any temperature level in July, in various groups of stations (referred to in Figure 3 and the text). Temperature standardized on R_m-scale.

as by the present author. This could be attributed to the fact that in terms of the variability, "within" stations, both the complete (and rather diversified) group of stations and the group consisting of continental stations only, hardly differ from each other. Both groups include some stations with a high internal variability and others with a low variability, but the group averages (S_w) for both groups are the same. Figure 7 shows that the average duration in both the complete group of 18 stations and the "continental" group, is also practically identical for all temperature levels. Consequently, the statistical distributions corresponding to these groups cannot differ considerably. This will be illustrated in a later section (Section 8).

Some other interesting groups of stations also emerged in the process of stratification discussed above. Some of them seem to be of real climatic significance, but at this stage of the study none can as yet be used in establishing a separate distribution model for a narrowly defined group of stations. A surprisingly close coincidence of average t-d patterns was found within such groups as the following (see Figure 5): (2)* Brownsville, Tex.; Mobile, Ala.; Savannah, Ga.; (3) Cape Hatteras, N.C.; Caribou, Me.; Key West, Fla.; Miami, Fla.; and San Diego, Calif. In group (2) the longest durations for all temperatures except the highest are uniformly shorter than in the continental group. In group (3) the opposite is true; whereas the short and medium durations are largely like those in the continental group, those above about 15 hours are consistently longer.

As the number of stations in each of these groups is small, these results may be regarded merely as indicative of some

* Class (1) consists of continental stations, as mentioned above.

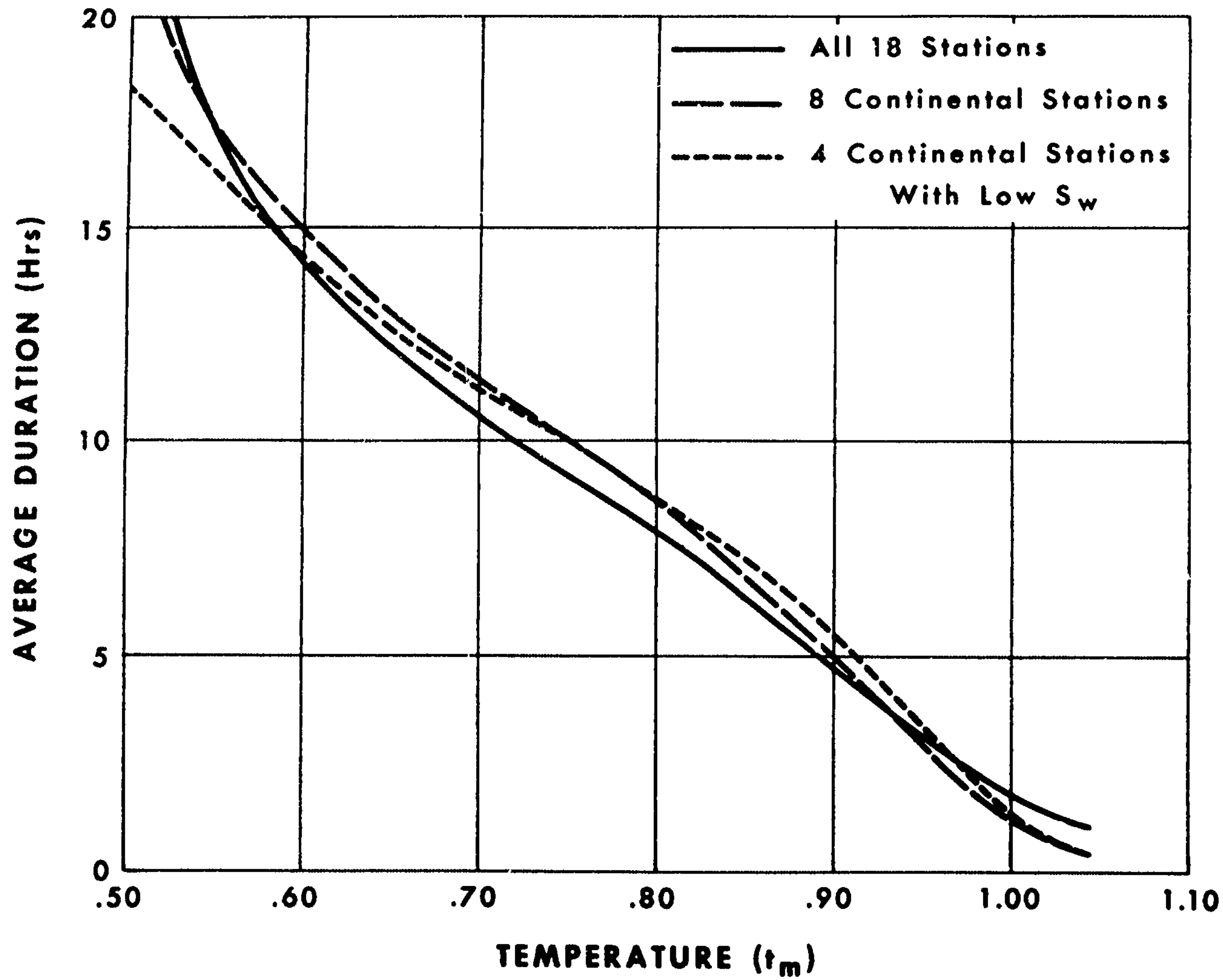


Figure 7. Average longest duration of temperature at or above any temperature level in July, in 3 different groups of stations (same stations as in Figure 6.

sort of classification and not as a basis. Also, the scatter within the stations in any of the groups is far from uniform; it tends to be so large that the potential improvement afforded by this approach is small.

A more significant improvement can be achieved by further separating stations within groups, but with a view to the variability "within" stations, rather than "between" them. The stratification alone would suffice if the mean longest durations were the only estimates desired. However, for determining durations for any given probability level, the variability "within" individual stations has to be considered as well. The latter reflects the extent to which the factors affecting the longest duration in a month are recurring uniformly from year to year. In some stations this variability is considerably lower than in others. Estimates in either of them could obviously be improved by adapting the breadth of the distribution to the variability of t-d's within stations. To achieve this, four stations were separated from the "continental" group, including those within which the longest t-d varies only little from year to year. These are Denver, Colo.; Phoenix, Ariz.; Spokane, Wash.; and Yuma, Ariz.

The effect of the last manipulation was quite impressive. For a considerable part of the temperature range, the standard deviation of the t-d variable is not more than 2 hours. For the t_m-range of 0.50-0.85 (corresponding to average durations of 6-18 hours), the standard deviation amounts to about 10-20% of the corresponding value of the average duration (see Figure 9). Practically, this means that the longest durations for stations of that type can be predicted to within very narrow limits (see Figure 12).

The difference between the internal variability of the four stations mentioned above and the remaining four is well reflected in the variability of the monthly maximum temperature,

S (t_{max}), as shown below. The latter value, which can be determined with relative ease for stations from standard published data, reflects the variability (between recurrent Julys) of the warm spells that affect the correspondingly longest t-d's. The value of S (t_{max}) given here (in degrees F) is related to the period 1951-1960 only, because the variability of the t-d's themselves has been evaluated from data for the same period.

Denver, Colo.	2.8°	Dayton, Ohio	4.0°
Phoenix, Ariz.	2.1°	Edmonton, Alta.	3.6°
Spokane, Wash.	3.0°	Knoxville, Tenn.	3.0°
Yuma, Ariz.	2.5°	Springfield, Mo.	4.9°

From these values it appears that Knoxville could probably have been included in the first class, but as it has similar distributional patterns this could not affect the pooled distribution obtained for the first group.

Other stations, for which the variability of the longest t-d in July has been found to be high, are given below, with the corresponding value of the standard deviation of the monthly maximum: Bethel, Alaska 4.8°; Seattle, Wash. 6.0°; San Diego, Calif. 4.2°; Caribou, Maine 4.1°; Edmonton, Alta. 3.6°. Other stations with low variability are: Brownsville, Tex. 2.4°; Savannah, Ga. 2.6°; Mobile, Ala. 2.2°; and Miami, Fla. 1.8°. The relationship between the variability of the longest monthly t-d and that of the extreme monthly temperature in July has not as yet been investigated beyond this point.

The preceding attempt indicates the approach for an effective refinement of the station stratification. The suggestion is to separate stations by the variability within them, thus

adapting the width of the corresponding distributions to the actual extent of the regularity of the t-d phenomenon in the stations concerned. Predictions for stations that have regularly recurrent weather patterns will be most favorably affected by having ranges of predicted t-d's reduced to a minimum. For other stations, predictions will be possible within wide ranges only. This, however, would not reflect any weakness of a prediction method, but rather the actual irregularity of climatic conditions of these stations.

The stratification of the January data was attempted with the same approach that was followed in the previously discussed case. There, a stratification by average distributional patterns was even less evident than in the July case. The reason was that the variability of the January t-d's "below" is considerably larger than that of the July t-d's "above" (see Fig. 4). This is true of the total variance and also of the variance "between" stations which, being so large, tends to obliterate even those grouping tendencies that may well exist. The larger variability calls for longer time series in studying the stratification of the January variable.

A grouping by internal variability was also attempted. Of the 19 stations included in the analysis of variance previously mentioned (Section 5), those with the highest and lowest internal variability of t-d's were separated. The first group included the stations listed below; for each station the value of the standard deviation of the monthly temperature $S(t_{min})$, in January is given (in parentheses) and some causal factors are mentioned that could well explain the variability of the t-d's concerned.

Bethel, Alaska (6.6°): Alternately affected by cold continental air and warm air from the Gulf of Alaska-Bering Sea areas.

Denver, Colorado (8.8°): Alternately affected by northerly and southerly flow associated with passage of cyclones and anticyclones; chinook winds.

Edmonton, Alberta (9.9°): Same as above; foehn winds.

Sydney, Nova Scotia (7°)

Spokane, Washington (12.8°)

The stations with the lowest variability include the following:

Honolulu, Hawaii (1.2°); distinctly maritime.

Miami, Florida (4.3°); distinctly maritime.

Phoenix, Arizona (2.3°); protected from extensive cold outbreaks.

San Diego, California (2.9°); maritime and protected from extensive cold outbreaks.

Savannah, Georgia (3.3°)

Yuma, Arizona (2.9°); protected from extensive cold outbreaks.

This grouping also brings out the predominant effect of latitude on the variability of extreme t-d's, which happens to be in good agreement with the findings of other investigations concerning monthly temperature (Anderson 1955, Thom 1956). In these studies, the variability of the mean monthly temperature has been found to decrease from north to south.

The remaining stations, which could not be unambiguously classified are: Brownsville, Tex.; Cape Hatteras, N.C.; Caribou, Me.; Dayton, Ohio; Knoxville, Tenn.; Mobile, Ala.; Salt Lake City, Utah; and Springfield, Mo.

The variance of the pooled distributions in each of the two extreme groups is presented in Figure 8 along with the

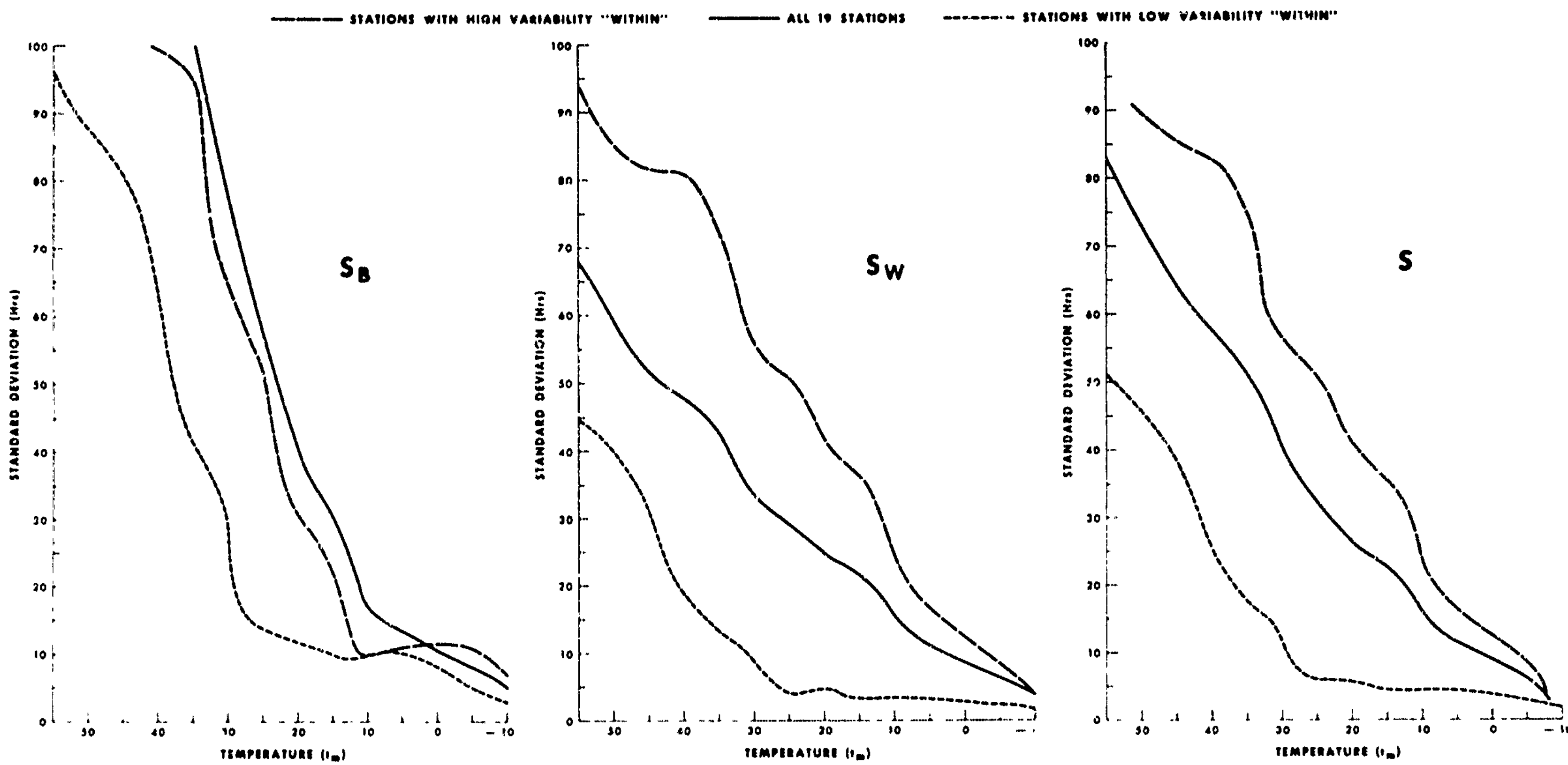


Figure 8. The variability of the longest duration at or below any temperature level in January, in various groups of stations (referred to in the text). Temperature standardized on R_m-scale.

variance of the combined group. The direct effect of this grouping is clearly brought out by the Sw-component. Incidentally, in the class of station with low variability the variance "between" is also favorably affected. The net effect, reflected in the S-graphs, is quite impressive and is even better illustrated in Figure 9. In the latter, the variability is related to the average duration. It shows that in terms of the relative standard deviation, the scatter of January t-d's "below", in stations of low internal variability, is only slightly higher than that of July t-d's "above". This is so at least for durations up to about 24 hours. In other words, if a station can be clearly defined as belonging to that class, t-d's can be predicted within a relatively narrow range.

For other stations, the scatter is as much as 2 to 3 times higher even when taken relative to the corresponding average duration. This is so both for the stations with the highest internal variability and probably also for most intermediate ones, as the variability in the complete group is only insignificantly smaller than that in the extreme group (see Fig. 9). It must therefore be concluded that for stations other than relatively "stable" ones, high year-to-year variability is an inherent feature of the longest duration of low temperature.

In conclusion, two grouping methods were attempted and evaluated in this section: a stratification by averages and a grouping by the variability within stations. Generally speaking, the data did not lend themselves very well to a stratification. Even some well defined groupings appeared to have little practical effect on the t-d distribution. However, this effect would probably be more significant if the averages of the separate groups had been more different from each other. This seems to be true of the January data,

but to investigate it, records of at least 20 years or more are needed. The length of record needed for each station can be economized by adapting it to the estimated variability of t-d's in the same stations.

Even where the practical value of the stratification can be doubted, it may well be of theoretical interest by adding a new aspect to the differentiation of climatic regimes. Some impressive similarities between distributional patterns at climatically similar stations were found. It seems, however, that for a more fundamental study in this direction, data for more stations are needed. For t-d's of low temperatures longer records of data are also required.

A more effective scheme of grouping the stations is that of separating stations with a low variability of t-d's from those with a high variability. Strictly speaking, this is not a stratification scheme in which uniformity of the <u>averages</u> within strata is the main concern. In grouping by the internal t-d variability, the size of confidence limits for expected durations is adapted to actual conditions at the stations concerned. For low variability stations, predictions within narrow ranges are made possible; for others, the width of the distribution will appropriately reflect the irregularity of recurring events. Also, there are strong indications that the t-d variability within stations is well reflected in the variability of monthly extreme temperatures.

Best possible results will be achieved by grouping the stations by internal t-d variability within an already stratified sample. Under these circumstances, both the averages and the scatter are made uniform within classes. The establishment of such a scheme should be the ultimate goal of any further study on the distribution of temperature durations from actual observations.

7. The Variability of Extreme Monthly Durations

In the foregoing sections the variability of extreme t-d's has been used in determining the effectiveness of certain treatments. This variability may be of interest in itself and it seems worthwhile to consider it briefly.

Two variables have been considered: the longest duration above given temperatures in July and below given temperatures in January. The latter was found to be very considerably larger, as shown in Figure 9 and in the following table:

Table VIII: The average variability of extreme monthly temperature durations at 19 stations in North America, 1951-1960. The January durations are those of low temperatures; the July durations are of high temperatures.

Average Duration (hrs)	2	4	6	8	10	12	14	16	18
Rel. std. dev. January	2.5	1.9	1.6	1.4	1.3	1.2	1.1	1.1	1.1
Rel. std. dev. July	1.2	.7	.4	.3	.2	.2	.3	.4	.5

Unlike daytime temperatures in summer, low temperatures in winter are not dominantly controlled by one factor that uniformly affects air temperature from year to year, such as the sun. Durations of low winter temperatures depend more on broad effects such as flow patterns, air mass evolution, and sometimes also on erratic local processes. The occurrence of any of these within one month is quite irregular. In fact, any specific situation that is liable to affect a long duration in a given area in the winter, can easily fail to occur during one particular month. Consequently, the longest duration below a given temperature may be 43 hours in a particular year, and only 3 hours in the following one (9°F at Dayton,

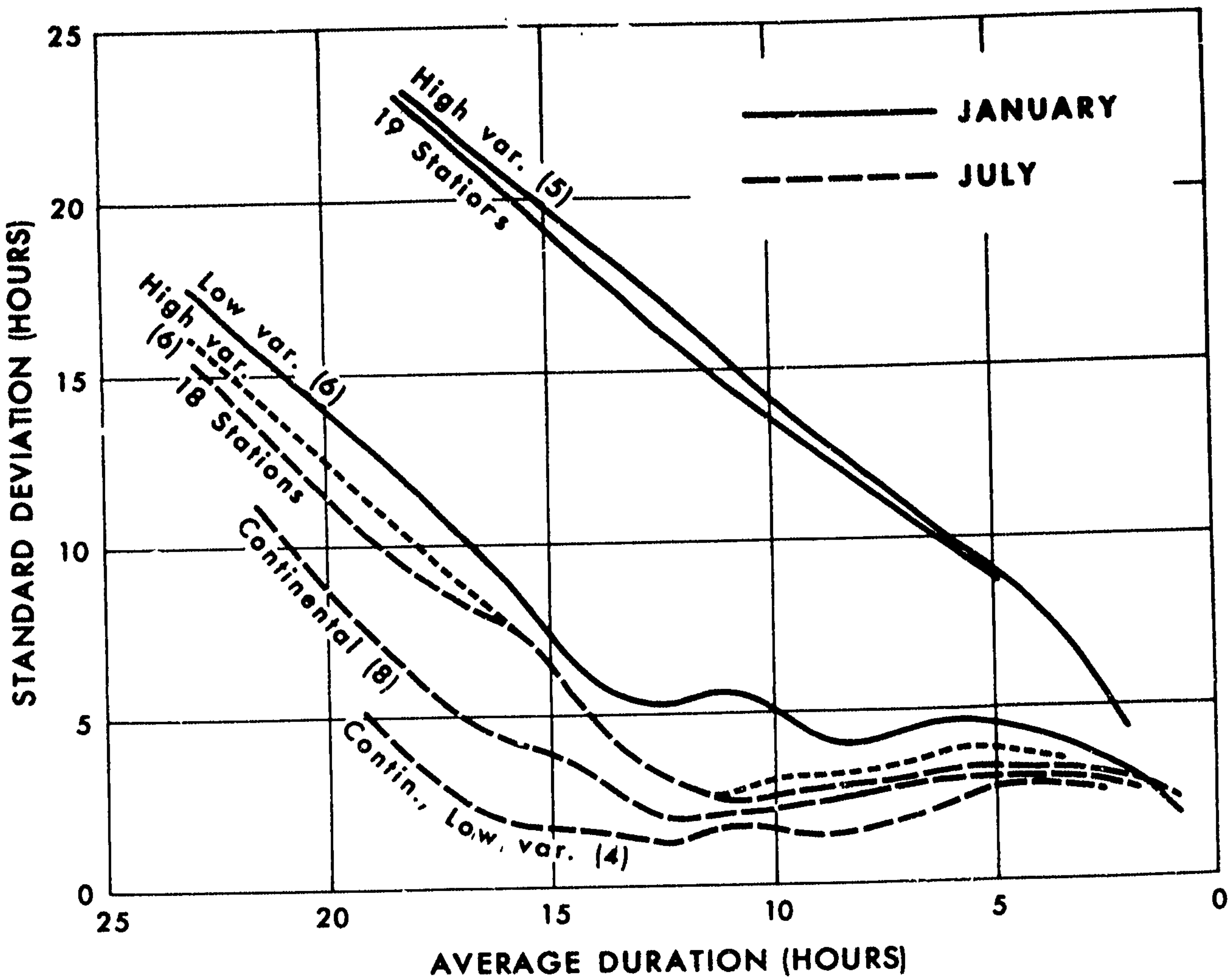


Figure 9. The variability of the longest duration of low temperatures in January and of medium and high ones in July in various classes of stations; the variability is related here to the mean duration. The classes of stations are listed in the text; their number in each class is given in parentheses. Temperature standardized on R_m-scale.

Ohio, 1959-1960; see Appendix A). Variations twice as large are also not uncommon.

Like any other climatic parameter, the variability of the longest monthly t-d also varies considerably between stations. Among those considered in this study so far, the lowest variability has been found in marine tropical stations, such as Honolulu, Hawaii; San Juan, Puerto Rico; and Miami, Florida. Relatively low variability is found even in the winter in stations that are effectively protected from large scale advection of well developed air masses. This is probably the case in southern Arizona (Phoenix and Yuma). Stations with high variability (in winter) include those that are affected alternately by two different air-masses or are subject to some other irregularity such as those at the periphery of cyclone tracks. Local features such as foehn winds can also affect t-d's. Data on the t-d variability in the stations treated can be found in Appendices A and B.

The larger variability of the January variable is mainly due to the fact that temperature in general is subject to a larger variability in the winter as compared to the summer (Thom, 1956; Anderson, 1955). Values of $S(t_{min})$ and $S(t_{max})$ obtained for the present study also indicate that these seasonal differences are more pronounced at night.

The variability of extreme monthly t-d's can be found directly only by obtaining the durations from the detailed hourly temperature record. However, as has been mentioned above, it can be estimated from the variability of extreme monthly temperature $S(t_{min})$ or $S(t_{max})$, respectively. The assumption is that the extreme monthly t-d is closely related to the monthly extreme temperature, and that the variability of either of them reflects the regularity with which weather patterns are recurring at a station in annual returns of a given month (e.g., July). This relationship between duration

and extreme temperature has been indicated by other authors and is further mentioned in the following section. At the stations included in the present study, a very good agreement has been found between the two parameters (see Section 6).

8. Estimated Model Distributions

For some of the station classes discussed in the preceding section, detailed distributions of the longest t-d have been worked out and are presented in this section. Within each of these classes, the t-d data from all stations have been pooled, using the R_m-standardization. A distribution thus derived is an average distribution over a period of time for all stations included. It is therefore an estimate of a "true" distribution pertaining to stations that would fall into the same class.

The distributions presented in this section illustrate various patterns, as different among themselves as possible within the scope of the data available for the study. Durations of highest and of lowest temperatures have been treated, as well as durations subject to high and low variability.

The distributions were plotted on a logarithmic duration scale because, in general, durations increase rapidly and can be more effectively dealt with on a logarithmic scale rather than on a linear scale. It was also felt that the accuracy of the duration values is more appropriately considered as a constant proportion of the corresponding average than in terms of a constant absolute value, of say ± 1 hour. The direction of temperature increase on the abscissa was so oriented as to have the mean temperature on the left-hand side and the extreme one, high or low as the case may be, on the right. Thus distribution patterns for both variables considered in this study can be more easily compared. It should be noted that almost no "smoothing" was done in drawing the percentile lines.

Some of the distributions presented can be used for practical purposes such as for determining the longest duration in a month, above a desired temperature at a given station, and at given probability levels. At this stage this can be done effectively only for July t-d's at continental stations. As the differences of the July variable between stations have been found to be relatively small, predictions for other stations may also be reasonably accurate. The January distributions could not be stratified so far as the variability between stations is very large. Therefore, their use is still hardly practical; at some stations very good results may be obtainable, but this cannot be determined beforehand. Reliable results can be obtained only for the lowest part of the temperature range, i.e., for t_m values from -0.05 to about 0.20.

The information necessary to make a "prediction" for a given station and month includes the monthly extreme temperatures (both maximum and minimum) for an adequate period of years. From these data the average monthly minimum $\bar{t}_{min}$ and average monthly range $\bar{R}_m$ are obtained for use in standardizing the temperature values. The standard deviation of the extreme monthly temperature (maximum for durations "above" and minimum for durations "below") is needed for more specific classification of a station. These are designated here $S(t_{max})$ and $S(t_{min})$.

The following is a discussion of the distributions presented. In all, six of them are included here (Figures 10-15), three for durations above given temperature levels in July, and three for durations below given levels in January. One distribution each for January and July, is an overall average for as many stations as could be included in each. Stations with unique distributions, such as San Francisco or Tatoosh Island, were omitted. Nevertheless, there still is considerable diversity in these two groups of stations. The other

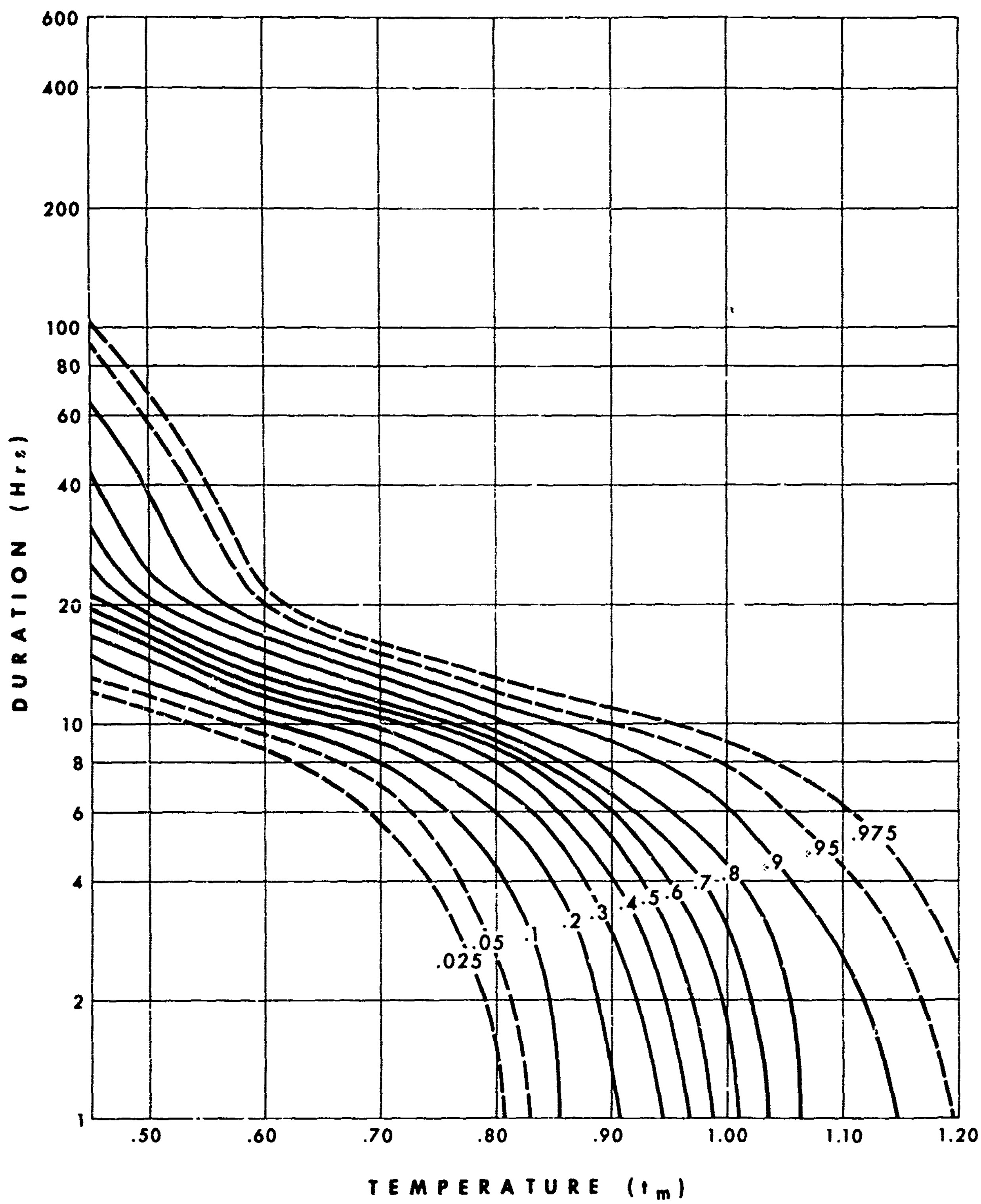


Figure 10. The average distribution of the longest uninterrupted duration at or above given temperatures in July, in 18 different stations in North America and the Pacific Ocean, 1951-1960 (see Section 6). Temperature given on R_m-scale.

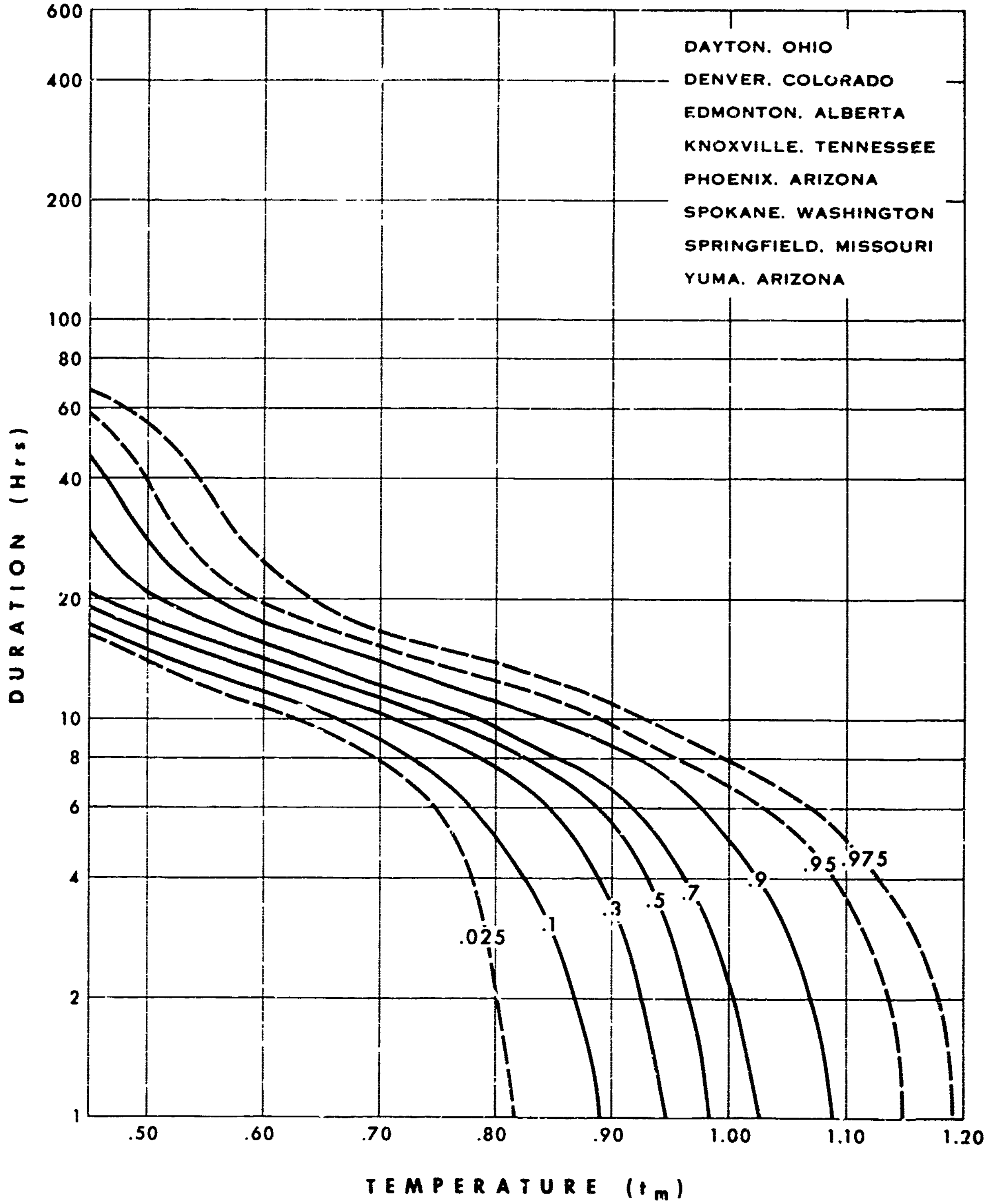


Figure 11. The average distribution of the longest uninterrupted duration at or above given temperatures in July in "continental" stations. Based on 8 stations in North America (see Section 6) and applies to stations in which the variability of the above duration is medium in size ($S(t_{max})$ 4°F).

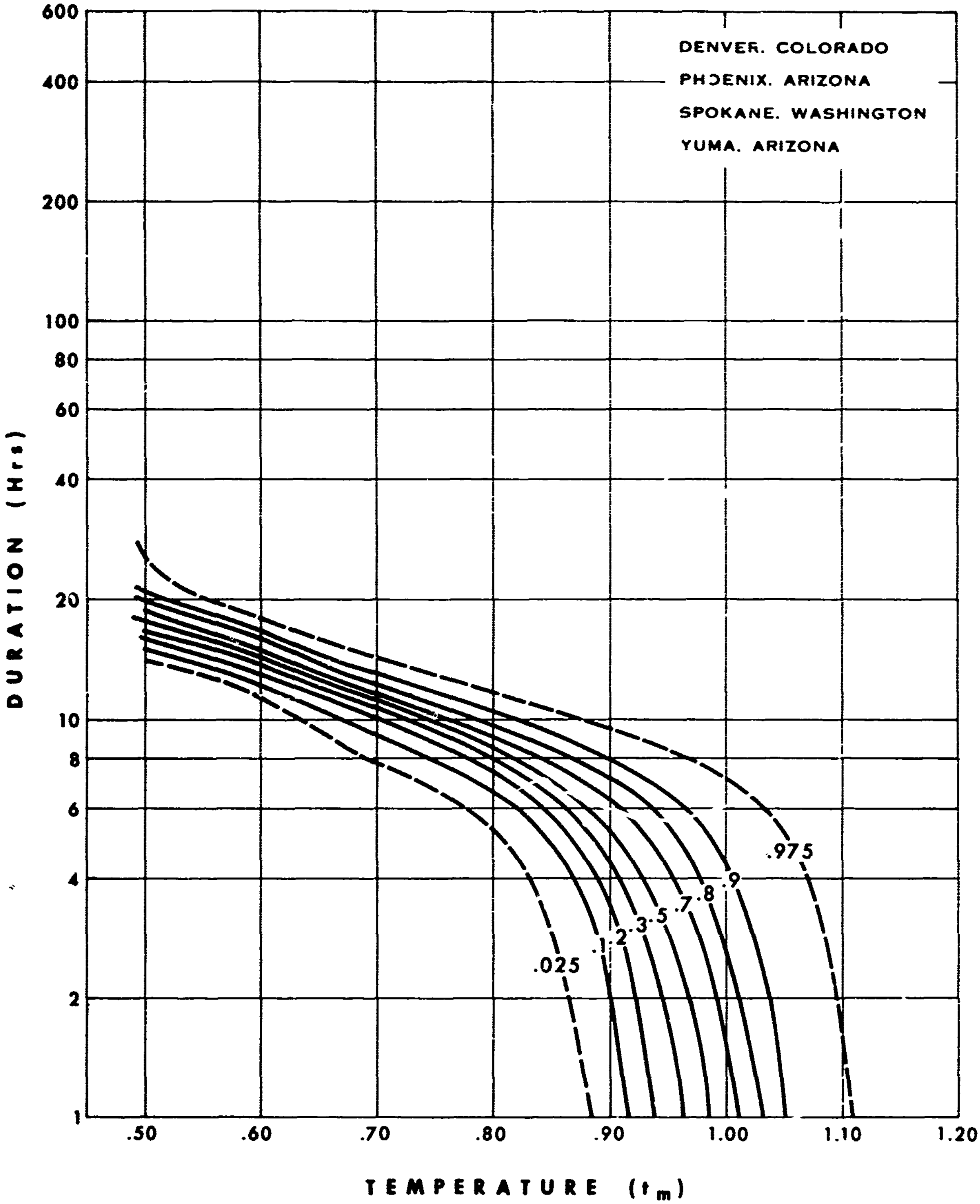


Figure 12. The distribution of the longest uninterrupted duration at or above given temperatures in July in "continental" stations, in which the variability of the above duration is low ($S(t_{max})$ approximately 2°-3°F).

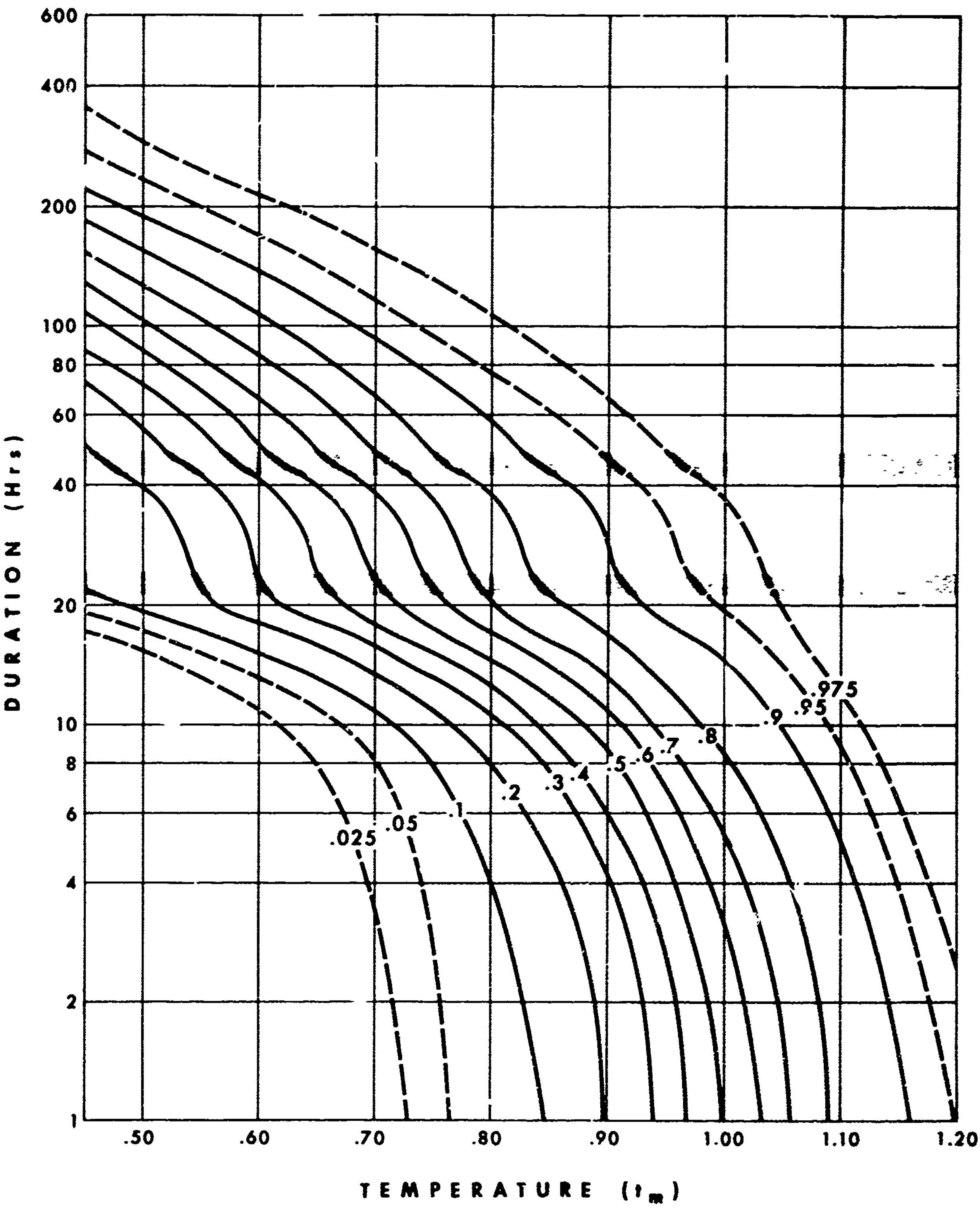


Figure 13. The average distribution of the longest uninterrupted duration at or below given temperatures in January, in 19 different stations in North America and the Pacific Ocean, 1951-1960 (see Section 6). Temperatures given on R_m-scale.

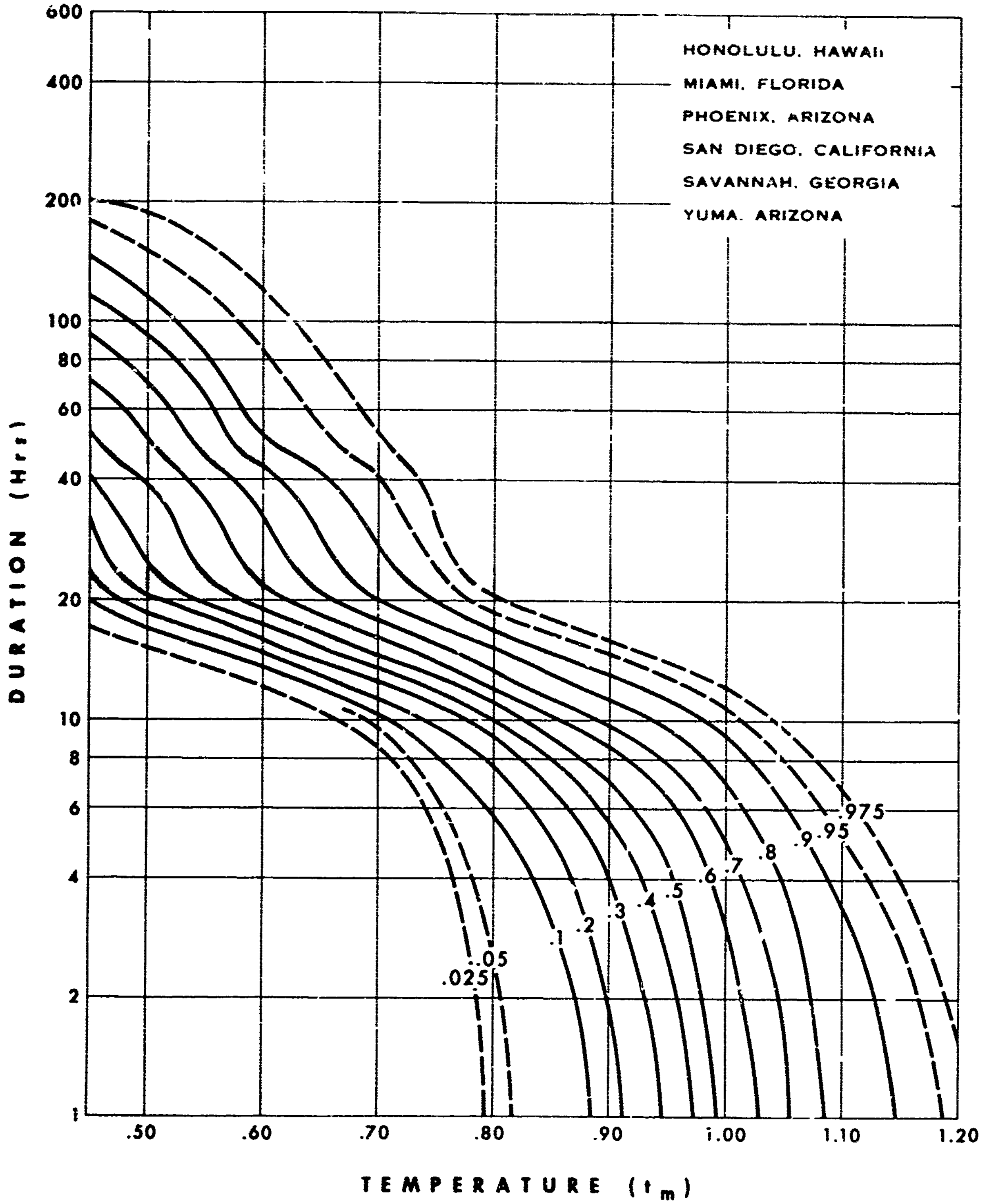


Figure 14. The average distribution of the longest uninterrupted duration at or below given temperatures in January, in 6 stations (see Section 6) in which the variability of the above duration is relatively low ($S(t_{min})$ approximately 2°-3°F).

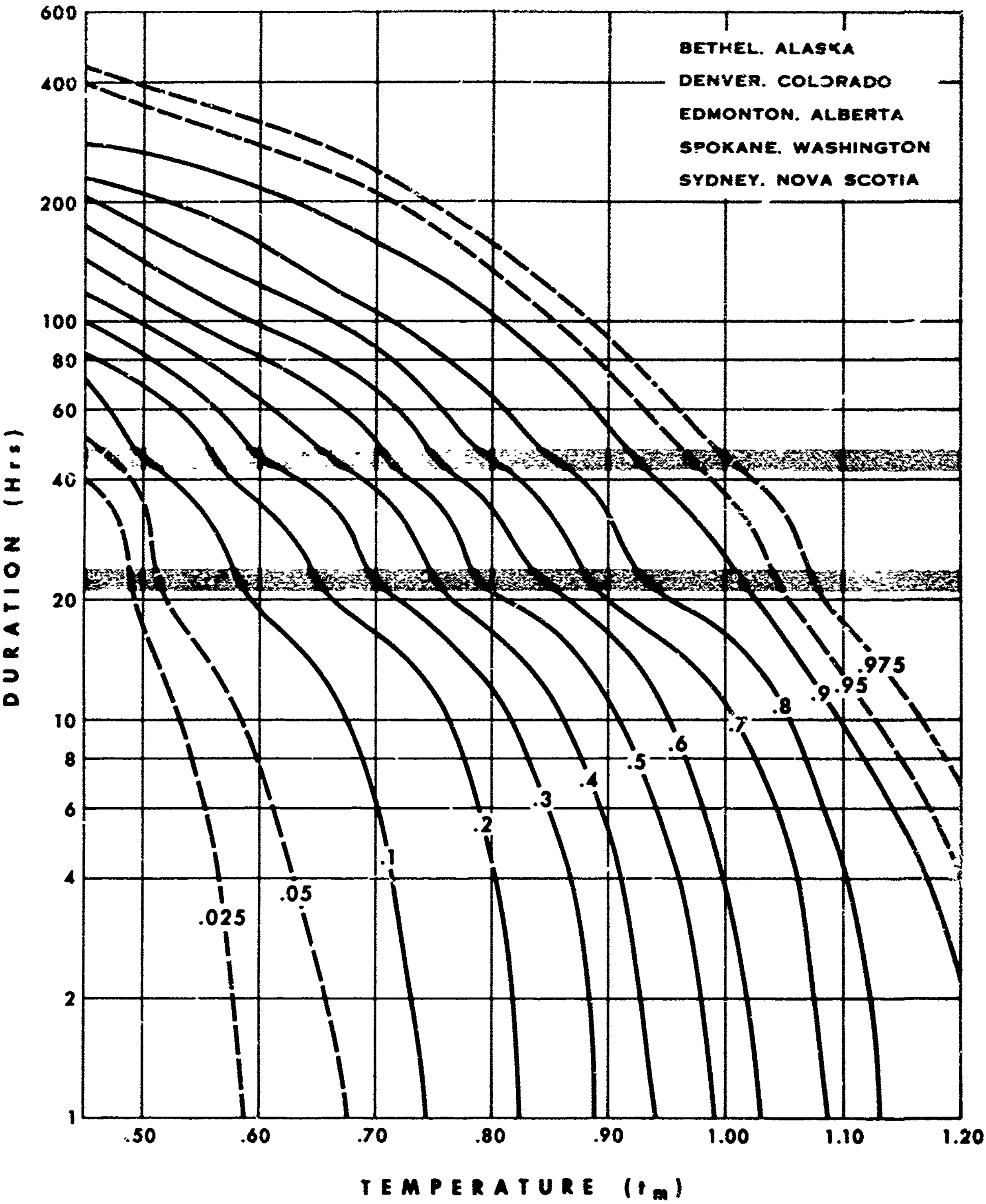


Figure 15. The average distribution of the longest uninterrupted duration at or below given temperatures in January in 5 stations (see Section 6) in which the variability of the above durations is high ($S(t_{min})$ 8°F).

distributions include two for more particular classes in each of the two months.

Two essential features are common to all six distributions. One is the linearity of the duration-increase with temperature-change in the range of durations from about 2 hours up to about 20 hours. This could be better brought out on a linear duration scale as in Figure 7, rather than on a logarithmic one. It was not further investigated here. This relationship has to do with the considerable uniformity of the temperature increase in the morning and decrease in the afternoon and evening on any particular day. The irregularities inherent in daily temperature charts are of a random character, and are eliminated when data for a considerable number of days are taken together. For two special cases, the linear relationship between duration and departure from the extreme temperature can also be found in data from other stations published previously by other authors (Court, 1952; Ganor, 1966).

The second feature is the scarcity of durations of about 24-36 hours and 48-60 hours. Obviously this is affected by the diurnal temperature cycle. A duration usually reaches 24 hours when approaching a daily temperature extreme, which is also a turning point of temperature change. Once it has passed the 24-hour mark, a duration could hardly terminate before approaching the extreme of the following day. The distributions are therefore "stretched" at these levels. In the graphical presentation of the distributions this is reflected by a rapid increase of durations just above the 24-hour and 48-hour duration levels.

Another characteristic of all distributions, not independent of the two already mentioned, is the fact that the relative variability of durations is smallest in the range of

about 12-20 hours. This means that the relative accuracy* of predicted values is higher in that range than for both higher or lower durations.

Outside the stretched parts, the distributions seem to be nearly symmetrical.

Turning to the distributions of July t-d's, reference is made to Figures 6 and 7, in which the variance of these distributions is analyzed. It is evident that the distributions differ only in scatter. The important fact, however, is that the scatter of each of the distributions is of the same order of magnitude as the corresponding variability of t-d's within stations. It follows that the error of predictions made from this type of distribution is minimized to its natural limit.

Figures 11 and 12 pertain to "continental" stations. Incidentally, since the distribution in Figure 10 has the same average as Figures 11 and 12, it can be applied also to continental stations that have higher internal variability, i.e., $S(t_{max})$ of about 5°F.

A tentative attempt to verify estimates obtained from the distributions was made using actual t-d data for continental stations from Westbrook's tables (1968). The result is shown in Table IX. The specific distributions used to make the estimates for July were determined from the standard deviation of the monthly maxima, $S(t_{max})$. The results show a high degree of agreement.

The distributions for the January variable (Figs. 13-15) are presented here mainly to illustrate their features as well as the problems involved in the prediction of durations of low temperatures. The variance in these distributions is analyzed in Figure 8, and the stations included are listed in Section 6.

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* Accuracy in terms of percent of mean duration.

The distributions show that the rate of increase in duration per unit of temperature change is invariably larger than that of durations of high temperatures. As a result, the average maximum duration below the monthly mean temperature in January is 50-100 hours long, as compared to 20 hours long, as compared to 20 hours or less for durations above the mean temperature in July. This has to do with the typical shape of the hourly temperature pattern around the daily extremes, in which temperature maxima are "peaked" whereas minima are "shallow" (e.g., on a thermogram). As a result, durations of low temperatures are much longer than those of high temperatures.

The large scatter of the January variable is reflected in each of the three distributions shown here. The scatter is smallest in Figure 14 and largest in Figure 15 (see also Figures 8 and 9). To bring out these extremes in scatter, the stations were grouped here by the variability of t-d's "within" them (see data in Appendix A), since the latter largely determines the total variability of the pooled distributions (see Fig. 8). The corresponding $S(t_{min})$ values were determined later, but they fitted the same grouping very well indeed (see Sec. 6). The narrower of these distributions gives an idea of the minimum size of confidence limits that can be produced for this variable by any method. Obviously, this applies to a special type of station only, whereas for most other stations the confidence limits will have to be considered wider. Figure 15 illustrates this convincingly. It should be noted that the variability in this group is not at all increased by differences between stations; consequently, the variability reflected in Figure 15 is that of actual occurrences in stations of that type. This means that natural conditions are such that even the most accurate t-d prediction that could be made for these stations by any method would

necessarily have an extremely broad range. Thus, a 90% range for the duration above a temperature corresponding to $t_m = 0.20$ (i.e., -17° in Bethel, +11° in Spokane) is 0-130 hours. Such predictions are obviously of lesser value than narrower ones, but when internal variability is high they are the best that can be hoped for. The accuracy of the foregoing prediction can be tested by checking actual occurrences at the stations mentioned (Appendix A) and also those at Fairbanks, Alaska, which belong to the same type (see Table IX). At Fairbanks, $t_m = 0.20$ corresponds to -30°.

Estimated t-d's were checked for a few more stations, the results of which are shown in Table IX. In view of the large scatter and the large absolute values of the durations involved, the result is impressive. However, though this may be indicative of the potential of the method as a whole, it does not constitute any sort of a test of the distributions.

9. Summary and Conclusions

The length of the period during which air temperature persists uninterruptedly above or below given values may affect military items and others more than such abstractions as temperature means, mean extremes and ranges. For this reason, the statistical distribution of the longest uninterrupted duration of temperature above or below any given value was studied from hourly temperature records from 25 stations. The purpose was to examine the temperature duration variable from different aspects and to explore the problems involved in the development of a general distribution-model. Besides its value for the development of an empirical model, this information is also essential for the study of theoretical models still being pursued by this author.

The distribution of temperature durations has been derived for some types of stations and can be used to make accurate predictions. The variability in these distributions was

Table IX. Test of estimates with actual data: 80% confidence limits of the longest duration below (in January) or above (in July) given temperatures, compared to actual occurrences in 8 out of 10 years, 1951-1960 (Westbrook, 1968). In parentheses are values of $S(t_{max})$ in July and $S(t_{min})$ in January. The specific distribution used is referred to by the figure number.

JULY - continental stations

Temperature (°F)	65°	70°	75°	80°	85°	90°	95°	100°	105°
Bismarck, N. D. (4.3) Fig. 11									
Estimated			14-23	11-17	9-14	5-11	1-9	0-5	0-1
Observed			15-21	11-16	8-12	6-9	0-7	0-5	0-0
Dallas, Texas (3.7) Fig. 11									
Estimated					15-27	11-16	6-11	0-8	0-5
Observed					18-21	13-16	8-12	2-9	0-6
Des Moines, Iowa (5.2) Fig. 10									
Estimated				13-19	9-15	5-11	1-8	0-4	
Observed				14-22	9-17	4-11	0-8	0-4	
Fairbanks, Alaska* (3.7) Fig. 11									
Estimated	13-20	10-15	6-12	1-9	0-6	0-1			
Observed	16-20	13-17	9-14	2-11	0-7	0-1			

JANUARY

Temperature (°F)	-40°	-35°	-30°	-10°	0°	10°	20°	30°	40°
Fairbanks, Alaska (8.4) Fig. 15									
Estimated	0-40	0-74	0-105						
Observed	0-57	0-62	3-102						
Des Moines, Iowa (3.6) Fig. 13									
Estimated				0-11	1-40	11-90			
Observed				0-9	13-18	24-92			
Dallas, Texas (5.6) Fig. 13									
Estimated							0-18	6-65	15-130
Observed							0-20	6-60	23-126
Fresno, California (3.0) Fig. 14									
Estimated								2-14	13-46
Observed								0-9	13-34

*1952-1961

reduced almost to the natural limit set by the variability in time inherent to durations in nature. This has been achieved by reducing actual temperature values to a uniform standard scale and by stratifying the sample of stations. Data for more stations are needed to widen the scope of the stratification scheme that has been started here. For further study of durations in winter months, data for 20 years or more are needed.

The distributional patterns of durations of high temperatures and of low temperatures have been shown to be quite different from each other. The latter are considerably longer and, in the winter, also much more variable from year to year. Such differences must be reflected in any distribution model to be suggested, whether empirical or with some other basis.

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APPENDIX A

Tables of longest uninterrupted duration of temperature at or below given values in January (R_m temperature standardization)

LONGEST UNINTERRUPTED DURATION OF TEMPERATURE *in January*
R(M) TEMP. STANDARDIZATION

BETHEL,ALASKA 1953-1962 (10 YRS)

TEMP'TURE T(M)	DEG	YR= 1	2	3	4	5	6	7	8	9	10	AVRG	VAR	STD DEV	REL STDEV
.55	7	215	277	131	267	134	225	338	223	95	237	214.2	5033.6	70.95	.33
.50	4	154	273	124	266	130	222	337	211	86	227	203.0	5548.6	74.49	.37
.45	0	103	196	114	264	47	212	331	173	82	224	174.6	7040.8	83.91	.48
.40	-3	90	154	111	240	21	143	261	149	47	190	140.6	5357.4	73.19	.52
.35	-7	76	149	108	233	17	117	249	142	42	176	130.9	5146.5	71.74	.55
.30	-10	73	88	106	208	14	106	48	138	32	143	95.6	3043.2	55.17	.58
.25	-13	71	63	101	186	0	75	20	134	14	121	78.5	3100.3	55.68	.71
.20	-17	43	49	96	64	0	50	4	132	0	97	53.5	1828.9	42.77	.80
.15	-20	42	44	94	18	0	40	1	104	0	61	40.4	1267.6	35.60	.88
.10	-23	18	31	61	12	0	35	0	36	0	18	21.1	354.3	18.82	.89
.05	-27	16	25	24	5	0	8	0	13	0	5	9.6	81.8	9.05	.94
0.00	-30	8	22	18	0	0	0	0	6	0	0	5.4	61.6	7.85	1.45
-.05	-33	0	15	14	0	0	0	0	2	0	0	3.1	32.9	5.73	1.85
-.10	-37	0	6	0	0	0	0	0	0	0	0	.6	3.2	1.80	3.00
-.15	-40	0	1	0	0	0	0	0	0	0	0	.1	.0	.30	3.00

BROWNSVILLE TEXAS 1951-1960 (10 YRS)

TEMP'TURE T(M)	DEG	YR= 1	2	3	4	5	6	7	8	9	10	AVRG	VAR	STD DEV	REL STDEV
.55	60	68	101	33	49	42	53	84	101	89	93	71.3	587.8	24.24	.34
.50	58	68	54	32	48	41	40	81	100	88	68	62.0	463.8	21.54	.35
.45	56	68	53	31	48	37	19	63	48	88	67	52.2	368.6	19.20	.37
.40	53	63	51	29	48	29	18	62	42	86	65	49.3	380.4	19.50	.40
.35	51	63	46	28	29	25	17	58	22	84	42	41.4	415.2	20.38	.49
.30	48	63	20	27	25	23	14	56	13	79	17	33.7	492.6	22.19	.66
.25	46	62	2	27	24	22	12	55	11	76	15	30.6	556.4	23.59	.77
.20	44	62	0	26	14	18	11	52	10	72	11	27.6	565.2	23.77	.86
.15	41	60	0	19	12	7	8	37	4	57	6	21.0	447.8	21.16	1.01
.10	39	59	0	0	7	0	4	27	0	55	0	15.2	499.0	22.34	1.47
.05	36	56	0	0	4	0	0	8	0	50	0	11.8	432.4	20.79	1.76
0.00	34	53	0	0	0	0	0	3	0	39	0	9.5	343.7	18.54	1.95
-.05	32	52	0	0	0	0	0	0	0	15	0	6.7	248.0	15.75	2.35
-.10	29	33	0	0	0	0	0	0	0			3.3	98.0	9.90	3.00
-.15	27	6	0	0	0	0	0	0	0			.6	3.2	1.80	3.00

C.HATTERAS ,N.C.   1953-1962   (10 YRS)

TEMP'TURE T(M)	DEG	YR= 1	2	3	4	5	6	7	8	9	10	AVRG	VAR	STD DEV	REL STDEV
.55	50	81	100	157	386	181	282	208	174	162	143	187.4	7153.6	84.58	.45
.50	48	72	78	112	324	180	280	139	172	114	120	159.1	6276.1	79.22	.50
.45	46	62	77	107	212	146	238	117	170	113	119	136.1	2841.3	53.30	.39
.40	44	48	67	61	191	108	206	117	159	113	97	116.7	2605.4	51.04	.44
.35	42	33	65	56	189	102	131	115	137	112	53	99.3	2047.8	45.25	.46
.30	40	28	63	55	114	100	118	106	93	112	51	84.0	916.8	30.28	.36
.25	38	11	39	28	72	79	73	61	83	68	42	55.6	526.4	22.94	.41
.20	36	7	38	27	61	46	60	59	42	43	36	41.9	249.3	15.79	.38
.15	34	2	37	16	42	22	55	55	21	38	17	30.5	279.9	16.73	.55
.10	32	0	16	10	18	18	27	36	11	18	13	16.7	85.4	9.24	.55
.05	30	0	13	6	10	15	16	33	8	10	10	12.1	67.5	8.22	.68
0.00	28	0	3	0	2	8	3	21	5	0	0	4.2	37.6	6.13	1.46
-.05	26	0	0	0	0	0	0	14	0	0	0	1.4	17.6	4.20	3.00
-.10	24	0	0	0	0	0	0	10	0	0	0	1.0	9.0	3.00	3.00
-.15	22	0	0	0	0	0	0	5	0	0	0	.5	2.3	1.50	3.00
-.20	20	0	0	0	0	0	0	2	0	0	0	.2	.4	.60	3.00

CARIBOU MAINE   1953-1962   (10 YRS)

TEMP'TURE T(M)	DEG	YR= 1	2	3	4	5	6	7	8	9	10	AVRG	VAR	STD DEV	REL STDEV
.55	12	71	170	98	60	251	69	88	178	217	110	131.2	4139.0	64.33	.49
.50	9	62	164	95	58	151	68	86	154	215	108	116.1	2476.3	49.76	.43
.45	6	24	104	94	36	103	65	81	105	142	105	85.9	1134.5	33.68	.39
.40	3	20	85	93	19	82	61	73	63	68	46	61.0	590.8	24.31	.40
.35	0	15	82	30	18	76	19	43	59	66	43	45.1	550.5	23.46	.52
.30	-3	10	75	28	11	72	17	20	57	64	41	39.5	592.7	24.34	.62
.25	-7	5	22	27	9	69	13	17	22	18	18	22.0	283.0	16.82	.76
.20	-10	0	19	12	7	67	9	7	17	17	15	17.0	308.6	17.57	1.03
.15	-13	0	17	10	5	65	0	4	13	10	11	13.5	322.3	17.95	1.33
.10	-16	0	15	6	0	64	0	1	7	9	7	10.9	334.9	18.30	1.68
.05	-19	0	7	5	0	18	0	0	0	9	2	4.1	31.5	5.61	1.37
0.00	-22	0	6	3	0	14	0	0	0	5	0	2.8	18.8	4.33	1.55
-.05	-25	0	2	0	0	10	0	0	0	2	0	1.4	8.8	2.97	2.12
-.10	-28	0	0	0	0	7	0	0	0	0	0	.7	4.4	2.10	3.00
-.15	-31	0	0	0	0	3	0	0	0	0	0	.3	.8	.90	3.00

DAYTON OHIO   1951-1960   (10 YRS)

TEMP'TURE T(M)	DEG	YR= 1	2	3	4	5	6	7	8	9	10	AVRG	VAR	STD DEV	REL STDEV
.55	34	143	156	124	137	240	356	294	140	207	163	196.0	5456.0	73.86	.38
.50	32	102	84	120	115	119	163	161	137	93	160	125.4	750.2	27.39	.22
.45	29	101	77	106	69	115	116	155	110	88	154	109.1	736.5	27.14	.25
.40	26	87	68	47	64	114	114	153	109	83	126	96.5	942.3	30.70	.32
.35	23	76	47	41	60	111	42	150	86	72	114	79.9	1158.7	34.04	.43
.30	20	69	41	21	52	109	19	147	23	69	44	59.4	1538.0	39.22	.66
.25	17	56	37	16	39	47	17	77	19	67	21	39.6	431.8	20.78	.52
.20	14	19	18	13	19	43	14	44	16	60	12	25.8	254.0	15.94	.62
.15	12	18	16	12	16	19	11	40	13	59	7	21.1	230.9	15.20	.72
.10	9	10	9	9	12	18	10	36	5	43	3	15.5	160.7	12.67	.82
.05	6	10	0	5	5	15	2	33	1	42	0	11.3	195.6	13.99	1.24
0.00	3	8	0	0	0	13	0	17	0	20	0	5.8	58.6	7.65	1.32
-.05	0	3	0	0	0	10	0	15	0	17	0	4.5	42.1	6.48	1.44
-.10	-3	0	0	0	0	7	0	8	0	14	0	2.9	22.5	4.74	1.64
-.15	-6	0	0	0	0	4	0	0	0	10	0	1.4	9.6	3.10	2.22
-.20	-8	0	0	0	0	2	0	0	0	8	0	1.0	5.8	2.41	2.41

DENVER COLORADO 1951-1960 (10 YRS)

TEMP'TURE T(M)	DEG	YR= 1	2	3	4	5	6	7	8	9	10	AVRG	VAR	STD DEV	REL STDEV
.55	34	120	82	47	112	165	80	183	66	84	226	116.5	2975.7	54.55	.47
.50	31	120	38	44	105	68	79	183	66	83	162	94.8	2077.8	45.58	.48
.45	28	119	37	42	65	46	58	182	66	76	91	78.2	1738.4	41.69	.53
.40	25	119	36	19	41	23	34	163	19	76	90	62.0	2155.0	46.42	.75
.35	22	119	35	17	40	18	33	108	18	76	69	53.3	1280.4	35.78	.67
.30	19	119	34	16	34	16	31	59	16	76	65	46.6	996.8	31.57	.68
.25	15	104	34	13	12	12	18	40	16	72	42	36.3	838.0	28.95	.80
.20	12	102	9	13	7	6	12	38	14	70	18	28.9	939.5	30.65	1.06
.15	9	101	6	12	6	0	9	22	14	53	17	24.0	851.6	29.18	1.22
.10	6	98	0	8	3	0	3	11	11	49	15	19.8	863.4	29.38	1.48
.05	3	59	0	2	0	0	0	8	5	45	13	13.2	402.6	20.06	1.52
0.00	0	55	0	0	0	0	0	2	1	41	11	11.0	362.2	19.03	1.73
-.05	-4	38	0	0	0	0	0	1	0	19	6	6.4	143.2	11.97	1.87
-.10	-7	16	0	0	0	0	0	0	0	10	1	2.7	28.4	5.33	1.97
-.15	-10	7	0	0	0	0	0	0	0	8	0	1.5	9.1	3.01	2.01
-.20	-13	5	0	0	0	0	0	0	0			.5	2.3	1.50	3.00

EDMONTON 1957-1965 (9 YRS)

TEMP'TURE T(M)	DEG	YR= 1	2	3	4	5	6	7	8	9	10	AVRG	VAR	STD DEV	REL STDEV
.55	10	201	51	369	191	102	192	130	145	211		176.9	7083.4	84.16	.48
.50	7	199	33	231	89	85	175	107	143	210		141.3	4004.9	63.28	.45
.45	4	198	15	184	86	65	124	102	140	209		124.8	3760.2	61.32	.49
.40	0	149	0	180	82	12	53	94	136	208		101.6	4672.5	68.36	.67
.35	-4	125	0	173	18	11	47	84	113	205		86.2	4794.4	69.24	.80
.30	-7	67	0	97	0	5	42	80	46	204		60.1	3699.9	60.83	1.01
.25	-10	22	0	52	0	1	39	55	43	203		46.1	3517.4	59.31	1.29
.20	-14	15	0	19	0	0	30	17	36	179		32.9	2819.7	53.10	1.61
.15	-18	7	0	15	0	0	25	7	14	168		26.2	2575.5	50.75	1.94
.10	-21	0	0	14	0	0	4	0	11	86		12.8	695.5	26.37	2.06
.05	-24	0	0	10	0	0	2	0	8	43		7.0	175.1	13.23	1.89
0.00	-28	0	0	8	0	0	0	0	1	17		2.9	31.0	5.57	1.93
-.05	-32	0	0	0	0	0				3		.3	.9	.94	2.83

HONOLULU HAWAII 1951-1960 (10 YRS)

TEMP'TURE T(M)	DEG	YR= 1	2	3	4	5	6	7	8	9	10	AVRG	VAR	STD DEV	REL STDEV
.55	73	22	24	20	40	20	17	43	69	45	20	32.0	254.4	15.95	.50
.50	72	21	22	20	18	17	16	37	21	20	17	20.9	32.5	5.70	.27
.45	71	20	13	20	16	16	12	35	18	18	16	18.4	36.8	6.07	.33
.40	70	18	13	18	16	15	12	19	18	17	15	16.1	4.9	2.21	.14
.35	69	14	12	15	14	14	11	16	16	16	14	14.2	2.6	1.60	.11
.30	68	13	11	13	13	11	11	13	15	15	13	12.8	2.0	1.40	.11
.25	68	13	11	13	13	11	11	13	15	15	13	12.8	2.0	1.40	.11
.20	67	12	10	13	11	10	10	7	11	15	12	11.1	4.1	2.02	.18
.15	66	11	9	13	11	9	9	7	11	14	11	10.5	3.9	1.96	.19
.10	65	7	8	13	10	8	7	6	10	11	11	9.1	4.5	2.12	.23
.05	64	6	8	10	9	8	5	5	7	8	10	7.6	3.0	1.74	.23
0.00	63	5	6	6	8	4	1	1	5	8	8	5.2	6.2	2.48	.48
-.05	62	4	5	5	5	3	0	0	1	5	8	3.6	6.0	2.46	.68
-.10	61	1	4	2	3	0	0	0	0	5	8	2.3	6.6	2.57	1.12
-.15	60	1	0	2	0	0	0	0	0	5	4	1.2	3.2	1.78	1.48
-.20	59	0	0	0	0	0	0			3	1	.4	.8	.92	2.29

KEY WEST, FLA. 1953-1964 (5 YRS)

TEMP'TURE T(M)	DEG	YR= 1	2	3	4	5	6	7	8	9	10	AVRG	VAR	STD DEV	REL STDEV
.55	69	72	104	94	108	81						91.8	185.0	13.60	.15
.50	68	68	102	94	108	81						90.6	209.4	14.47	.16
.45	67	45	101	86	108	81						84.2	479.8	21.90	.26
.40	65	43	100	64	69	65						68.2	335.0	18.30	.27
.35	64	41	65	50	38	63						51.4	121.8	11.04	.21
.30	62	26	39	46	18	60						37.8	218.6	14.78	.39
.25	61	22	36	38	14	58						33.6	227.8	15.09	.45
.20	60	21	36	31	8	50						29.2	199.8	14.13	.48
.15	58	15	30	18	3	45						22.2	203.8	14.27	.64
.10	57	12	29	12	1	40						18.8	192.6	13.88	.74
.05	55	3	15	5	0	30						10.6	119.4	10.93	1.03
0.00	54	0	11	1	0	29						8.2	125.4	11.20	1.37
-.05	53	0	2	0	0	20						4.4	61.4	7.84	1.78
-.10	51	0	0	0	0	11						2.2	19.4	4.40	2.00
-.15	50	0	0	0	0	9						1.8	13.0	3.60	2.00
-.20	48	0	0	0	0	2						.4	.6	.80	2.00

KNOXVILLE TENN 1951-1960 (10 YRS)

TEMP'TURE T(M)	DEG	YR= 1	2	3	4	5	6	7	8	9	10	AVRG	VAR	STD DEV	REL STDEV
.55	44	66	78	126	129	160	254	138	233	177	167	152.8	3214.6	56.70	.37
.50	42	64	68	124	128	85	186	114	228	177	166	134.0	2660.6	51.58	.38
.45	39	53	66	81	119	79	141	113	116	176	164	110.8	1534.0	39.17	.35
.40	36	52	63	57	110	40	96	112	71	87	138	82.6	880.8	29.68	.36
.35	33	45	40	48	85	20	39	82	47	81	108	59.5	683.1	26.14	.44
.30	31	21	38	24	72	18	21	63	45	78	56	43.6	461.4	21.48	.49
.25	28	16	35	18	40	14	12	44	43	56	40	31.8	215.4	14.68	.46
.20	25	11	18	4	27	9	10	42	19	54	19	21.3	223.6	14.95	.70
.15	22	10	15	0	17	8	7	20	16	33	16	14.2	71.2	8.44	.59
.10	20	5	14	0	17	8	0	11	15	31	12	11.3	74.8	8.65	.77
.05	17	4	11	0	14	5	0	9	10	26	3	8.2	55.2	7.43	.91
0.00	14	0	0	0	11	0	0	6	8	16	0	4.1	30.9	5.56	1.36
-.05	11	0	0	0	1	0	0	0	2	6	0	.9	3.3	1.81	2.02
-.10	9	0	0	0	0	0				5	0	.5	2.3	1.50	3.00

MIAMI FLA. 1951-1960 (10 YRS)

TEMP'TURE T(M)	DEG	YR= 1	2	3	4	5	6	7	8	9	10	AVRG	VAR	STD DEV	REL STDEV
.55	64	56	20	41	40	42	116	19	92	65	137	62.8	1441.8	37.97	.60
.50	62	43	19	39	17	41	71	19	90	65	112	51.6	934.6	30.57	.59
.45	60	32	17	36	16	40	46	19	68	63	92	42.9	559.5	23.65	.55
.40	58	20	16	25	14	36	19	19	66	44	45	30.4	257.0	16.03	.53
.35	56	20	14	15	12	18	18	18	59	40	21	23.5	193.7	13.92	.59
.30	54	17	13	15	11	15	17	13	45	19	19	18.4	84.8	9.21	.50
.25	53	17	13	13	9	14	16	12	23	18	18	15.3	14.0	3.74	.24
.20	51	14	11	11	8	12	15	5	17	17	17	12.7	15.0	3.87	.31
.15	49	13	8	9	5	8	14	3	14	16	16	10.6	19.2	4.39	.41
.10	47	12	6	5	4	6	12	0	13	13	14	8.5	21.3	4.61	.54
.05	45	10	1	1	2	5	10	0	11	9	12	6.1	20.5	4.52	.74
0.00	43	9	0	0	0	3	9	0	10	7	10	4.8	19.0	4.35	.91
-.05	41	7	0	0	0	0	0	0	6	3	8	2.4	10.0	3.17	1.32
-.10	39	5	0	0	0	0	0	0	1	0	5	1.1	3.9	1.97	1.79
-.15	37	1	0	0	0	0	0	0	0		2	.3	.4	.64	2.13

PHOENIX ARIZ 1951-1960 (10 YRS)

TEMP'TURE T(M)	DEG	YR= 1	2	3	4	5	6	7	8	9	10	AVRG	VAR	STD DEV	REL STDEV
.55	55	66	46	44	44	140	40	55	18	23	164	64.0	2135.8	46.21	.72
.50	53	49	21	21	23	139	21	52	17	19	160	52.2	2528.0	50.28	.96
.45	51	22	20	18	18	44	20	51	17	17	158	38.5	1718.9	41.46	1.08
.40	48	19	17	11	17	20	16	26	14	15	45	20.0	83.8	9.15	.46
.35	46	17	16	11	16	18	13	25	13	13	42	18.4	75.6	8.70	.47
.30	44	16	16	10	14	16	11	24	13	12	19	15.1	15.5	3.94	.26
.25	42	15	14	10	12	13	10	13	11	10	17	12.5	5.1	2.25	.18
.20	39	14	13	8	11	11	5	6	9	8	15	10.0	10.2	3.19	.32
.15	37	13	10	7	8	8	5	4	8	6	13	8.2	8.4	2.89	.35
.10	35	9	9	5	6	7	2	1	4	4	10	5.7	8.4	2.90	.51
.05	32	7	7	0	3	5	0	0	3	0	7	3.2	8.8	2.96	.92
0.00	30	0	5	0	0	2	0	0	0	0	2	.9	2.5	1.58	1.75
-.05	28	3	0	0	0	0	0	0	0			.3	.8	.90	3.00

SALT L. CTY 1951-1960 (10 YRS)

TEMP'TURE T(M)	DEG	YR= 1	2	3	4	5	6	7	8	9	10	AVRG	VAR	STD DEV	REL STDEV
.55	28	81	133	17	22	136	31	91	18	81	153	76.3	2483.8	49.84	.65
.50	26	80	132	16	16	116	30	68	17	61	152	68.8	2309.6	48.06	.70
.45	23	78	109	8	15	69	30	24	15	42	134	52.4	1697.8	41.20	.79
.40	21	76	108	2	15	21	16	19	14	38	133	44.2	1852.0	43.03	.97
.35	18	30	85	0	11	20	14	17	10	21	90	29.8	889.2	29.82	1.00
.30	16	30	44	0	11	18	9	17	5	18	47	19.9	224.9	15.00	.75
.25	13	15	22	0	2	16	8	16	4	14	43	14.0	139.0	11.79	.84
.20	11	13	19	0	0	15	8	15	2	14	20	10.6	52.0	7.21	.68
.15	8	6	16	0	0	14	4	13	0	11	12	7.6	36.0	6.00	.79
.10	6	3	14	0	0	12	0	13	0	11	8	6.1	33.1	5.75	.94
.05	3	0	8	0	0	2	0	9	0	5	6	3.0	12.0	3.46	1.15
0.00	1	0	0	0	0	1	0	4	0	2	4	1.1	2.5	1.58	1.43
-.05	-1	0	0	0	0	0					3	.3	.8	.90	3.00

MOBILE ALA 1951-1960 (10 YRS)

TEMP'TURE T(M)	DEG	YR= 1	2	3	4	5	6	7	8	9	10	AVRG	VAR	STD DEV	REL STDEV
.55	53	63	44	58	85	68	118	108	226	88	164	107.2	2797.4	52.89	.52
.50	51	56	38	53	84	66	68	87	138	75	163	82.8	1367.4	36.98	.45
.45	49	55	36	52	82	61	67	84	137	74	68	71.6	661.8	25.73	.36
.40	46	54	23	50	44	36	64	61	95	73	66	56.6	366.8	19.15	.34
.35	44	21	21	49	43	32	63	59	91	73	46	49.8	453.2	21.29	.43
.30	41	19	16	27	19	31	14	55	44	57	40	32.2	230.6	15.18	.47
.25	39	16	15	19	17	30	10	52	42	53	18	27.2	233.4	15.28	.56
.20	37	14	12	10	14	29	9	50	41	44	17	24.0	220.4	14.85	.62
.15	34	13	9	3	10	9	8	19	18	19	15	12.3	26.2	5.12	.42
.10	32	11	7	0	8	8	8	15	16	17	13	10.3	24.0	4.90	.48
.05	29	6	1	0	0	0	4	13	12	13	10	5.9	28.7	5.36	.91
0.00	27	0	0	0	0	0	1	10	9	12	8	4.0	23.0	4.80	1.20
-.05	25	0	0	0	0	0	0	4	6	4	6	2.0	6.4	2.53	1.26
-.10	22	0	0	0	0	0	[illegible]		1	0	1	.2	.2	.40	2.00

SAVANNAH, GA. 1951-1960 (10 YRS)

TEMP'TURE T(M)	DEG	YR= 1	2	3	4	5	6	7	8	9	10	AVRG	VAR	STD DEV	REL STDEV
.55	54	135	78	62	71	91	141	135	219	77	182	119.1	2474.7	49.75	.42
.50	52	65	78	60	70	68	118	132	217	76	180	106.4	2683.6	51.80	.49
.45	49	64	67	56	68	65	67	121	215	75	117	91.5	2151.7	46.39	.51
.40	46	43	44	45	41	55	41	94	143	74	116	69.6	1197.2	34.60	.50
.35	44	41	23	21	39	49	33	70	115	47	47	48.5	668.3	25.85	.53
.30	41	18	20	15	38	45	22	66	63	45	43	37.5	303.9	17.43	.46
.25	39	17	18	14	19	19	20	24	23	43	21	21.8	57.4	7.57	.35
.20	36	14	14	11	14	13	14	16	20	40	19	17.5	62.9	7.93	.45
.15	34	14	13	10	12	11	10	16	18	20	17	14.1	11.1	3.33	.24
.10	31	10	9	7	5	9	9	14	15	17	14	10.9	13.5	3.67	.34
.05	29	10	7	5	3	9	6	12	14	15	13	9.4	15.0	3.88	.41
0.00	26	5	5	0	0	5	4	11	11	13	10	6.4	19.2	4.39	.69
-.05	23	0	0	0	0	1	1	9	5	10	6	3.2	14.2	3.76	1.18
-.10	21	0	0	0	0	0	0	4	0	7	3	1.4	5.4	2.33	1.67
-.15	18	0	0	0	0	0	0	1	0	4	0	.5	1.5	1.20	2.41

SAN DIEGO, CAL 1951-1960 (10 YRS)

TEMP'TURE T(M)	DEG	YR= 1	2	3	4	5	6	7	8	9	10	AVRG	VAR	STD DEV	REL STDEV
.55	59	151	108	43	69	94	67	139	19	18	184	89.2	2869.6	53.57	.60
.50	58	81	68	43	47	93	43	94	17	16	66	56.8	721.6	26.86	.47
.45	56	26	21	18	42	23	19	90	15	13	47	31.4	493.8	22.22	.71
.40	54	16	20	17	21	21	16	47	13	11	19	20.1	90.3	9.50	.47
.35	52	15	17	14	19	20	14	22	12	8	18	15.9	15.5	3.94	.25
.30	50	15	16	12	11	15	13	17	9	5	17	13.0	13.4	3.66	.28
.25	48	13	15	9	9	12	8	11	8	4	14	10.3	10.0	3.16	.31
.20	46	10	13	8	7	10	5	9	6	0	13	8.1	13.7	3.70	.46
.15	45	9	12	4	6	9	5	9	5	0	11	7.0	12.0	3.46	.49
.10	43	8	11	1	3	5	2	4	2	0	9	4.5	12.3	3.50	.78
.05	41	4	8	0	0	2	0	0	0	0	7	2.1	8.9	2.98	1.42
0.00	39	0	6	0	0	0	0	0	0	0	3	.9	3.7	1.92	2.13

SAN FRANC. 1951-1960 (10 YRS)

TEMP'TURE T(M)	DEG	YR= 1	2	3	4	5	6	7	8	9	10	AVRG	VAR	STD DEV	REL STDEV
.59	51	84	231	25	68	237	47	166	44	22	63	96.7	6057.2	77.83	.79
.53	49	47	85	24	42	70	32	141	21	21	61	54.4	1258.8	35.48	.65
.50	48	44	44	23	39	66	23	140	19	18	42	45.8	1188.0	34.47	.75
.46	47	41	43	22	37	24	20	115	17	18	42	37.9	759.7	27.56	.73
.43	46	41	43	18	28	16	17	114	15	16	20	32.8	830.2	28.81	.88
.36	44	19	21	13	26	15	9	22	14	15	19	17.3	22.6	4.75	.27
.32	43	17	20	13	24	12	9	16	14	12	19	15.6	18.2	4.27	.27
.25	42	11	19	12	14	9	8	15	9	11	18	12.6	13.0	3.61	.29
.21	40	10	12	4	13	9	7	13	8	8	16	10.0	11.2	3.35	.33
.18	39	10	11	2	12	9	2	11	7	7	15	8.6	15.8	3.98	.46
.14	38	8	11	2	10	9	0	10	6	2	13	7.1	17.5	4.18	.59
.07	36	7	9	0	8	8	0	7	0	0	10	4.9	16.7	4.09	.83
.03	35	5	9	0	4	8	0	3	0	0	9	3.8	13.2	3.63	.95
.00	34	4	8	0	4	6	0	3	0	0	8	3.3	9.6	3.10	.94

SPOKANE WASH 1951-1960 (10 YRS)

TEMP'TURE T(M)	DEG	YR= 1 2 3 4 5 6 7 8 9 10	AVRG VAR STD DEV	REL STDEV
.55	27	122109 13154 67151464 71111412	167.420011.4141.46	.95
.50	25	121 96 4153 42128440 67109354	151.417149.6130.96	.86
.45	22	119 96 0153 19108439 11105162	121.214202.8119.18	.98
.40	20	118 96 0153 17 79427 6103118	111.713520.8116.28	1.04
.35	18	116 96 0 75 15 77363 3 98 91	93.4 9687.8 98.43	1.05
.30	16	104 83 0 74 12 56255 0 90 87	76.1 4924.3 70.17	.92
.25	13	55 36 0 67 2 32185 0 66 22	46.5 2728.1 52.23	1.12
.20	11	20 35 0 46 0 22139 0 64 19	34.5 1610.1 40.13	1.16
.15	9	20 34 0 41 0 20 91 0 59 12	27.7 787.0 28.05	1.01
.10	7	16 34 0 21 0 19 67 0 22 11	19.1 370.5 19.25	1.01
.05	4	12 18 0 19 0 17 66 0 19 7	15.8 338.8 18.41	1.16
0.00	2	9 13 0 18 0 17 37 0 15 3	11.2 121.2 11.01	.98
-.05	0	4 11 0 16 0 16 36 0 13 1	9.7 117.4 10.84	1.12
-.10	-3	0 10 0 9 0 11 19 0 9 0	5.8 40.8 6.38	1.10
-.15	-5	0 8 0 7 0 9 18 0 4 0	4.6 32.2 5.68	1.23
-.20	-7	0 4 0 3 0 3 16 0 0 0	2.6 22.2 4.72	1.81

SPRINGFLD MO. 1951-1960 (10 YRS)

TEMP'TURE T(M)	DEG	YR= 1 2 3 4 5 6 7 8 9 10	AVRG VAR STD DEV	REL STDEV
.55	38	115169105151113163154114126250	146.0 1687.8 41.08	.28
.50	35	114159 73140 88160149 91100249	132.3 2400.0 48.99	.37
.45	32	113156 71113 66133142 61 93159	110.7 1223.0 34.97	.32
.40	29	113 67 69 70 30128111 45 90 83	80.6 857.4 29.28	.36
.35	25	105 32 34 50 26 54105 37 88 57	58.8 811.0 28.48	.48
.30	22	95 20 30 45 25 41 56 34 66 42	45.4 445.6 21.11	.46
.25	19	92 16 19 43 21 35 41 17 63 17	36.4 557.4 23.61	.65
.20	16	92 13 16 39 15 31 37 15 60 14	33.2 596.4 24.42	.74
.15	13	91 9 12 25 12 21 15 12 58 13	26.8 643.6 25.37	.95
.10	9	27 2 6 6 7 10 11 0 55 10	13.4 240.4 15.51	1.16
.05	6	15 0 0 2 4 7 9 0 23 0	6.0 54.4 7.33	1.23
0.00	3	9 0 0 0 0 1 5 0 17 0	3.2 29.4 5.42	1.69
-.05	0	5 0 0 0 0 0 0 0 12 0	1.7 14.0 3.74	2.20
-.10	-3	0 0 0 0 0 0 6 0	.6 3.2 1.80	3.00

SEATTLE WASH. 1951-1960 (10 YRS)

TEMP'TURE T(M)	DEG	YR= 1 2 3 4 5 6 7 8 9 10	AVRG VAR STD DEV	REL STDEV
.65	43	171445 81499274225464 69152469	284.925997.1161.24	.57
.59	41	128350 46433142202344 22128420	221.621040.0145.05	.65
.56	40	127349 45432 46154321 19127207	182.718099.8134.54	.74
.50	38	127181 22167 41152318 16105110	123.9 7304.1 85.46	.69
.47	37	125180 21165 37127291 10104107	116.7 6404.6 80.03	.69
.41	35	123106 16146 17 80230 8104 72	90.2 4223.0 64.98	.72
.38	34	121 96 15146 16 70190 6103 25	78.8 3583.0 59.86	.76
.32	32	120 61 11 82 5 25132 3 81 16	53.6 2113.6 45.97	.86
.29	31	82 61 11 75 5 22131 2 81 14	46.4 1621.2 40.26	.87
.23	29	57 36 3 74 0 19127 0 78 11	40.5 1632.3 40.40	1.00
.20	28	55 36 0 73 0 18106 0 77 6	37.1 1341.1 36.62	.99
.15	26	52 13 0 20 0 15 45 0 61 4	21.0 485.0 22.02	1.05
-.12	25	29 13 0 19 0 14 44 0 55 0	17.4 350.0 18.71	1.08
-.06	23	26 12 0 15 0 9 19 0 22 0	10.3 91.0 9.54	.93
-.03	22	24 11 0 15 0 6 18 0 20 0	9.4 79.8 8.94	.95
-.03	20	11 10 0 10 0 3 16 0 17 0	6.7 42.6 6.53	.97

SYDNEY, N. SCOT. 1957-1966 (10 YRS)

TEMP'TURE T(M)	DEG	YR= 1	2	3	4	5	6	7	8	9	10	AVRG	VAR	STD DEV	REL STDEV
.55	26	189	84	202	81	262	109	72	209	88	77	137.3	4469.2	66.85	.49
.50	24	186	82	159	80	261	88	70	147	69	43	118.5	4156.3	64.47	.54
.45	21	90	43	85	77	257	73	67	73	58	42	86.5	3460.5	58.83	.68
.40	19	89	27	55	41	256	71	40	69	42	40	73.0	4036.8	63.54	.87
.35	17	66	14	53	40	217	70	22	63	41	39	62.5	2954.3	54.35	.87
.30	14	63	8	50	38	142	65	16	37	40	36	49.5	1238.5	35.19	.71
.25	12	62	4	44	36	140	64	13	19	35	16	43.3	1405.0	37.48	.87
.20	10	60	0	35	33	93	37	11	16	35	13	33.3	661.4	25.72	.77
.15	8	58	0	30	30	67	20	0	0	32	0	23.7	546.0	23.37	.99
.10	5	36	0	19	17	55	18	0	0	30	0	17.5	313.3	17.70	1.01
.05	3	31	0	12	0	51	17	0	0	29	0	14.0	287.6	16.96	1.21
0.00	0	16	0	4	0	28	15	0	0	26	0	8.9	116.5	10.79	1.21
-.05	-2	8	0	0	0	9	13	0	0	11	0	4.1	26.7	5.17	1.26
-.10	-4	6	0	0	0	5	3	0	0	5	0	1.9	5.9	2.43	1.28
-.15	-7	0	0	0	0	2	0	0	0	0	0	.2	.4	.60	3.00

YUMA ARIZ 1953-1962 (10 YRS)

TEMP'TURE T(M)	DEG	YR= 1	2	3	4	5	6	7	8	9	10	AVRG	VAR	STD DEV	REL STDEV
.55	58	38	19	115	16	95	17	19	118	17	68	52.2	1655.0	40.68	.78
.50	56	18	18	93	15	92	16	17	110	16	67	46.2	1403.2	37.46	.81
.45	53	15	17	67	13	32	14	15	66	15	37	29.1	409.9	20.25	.70
.40	51	12	16	43	13	20	13	15	21	14	35	20.2	99.4	9.97	.49
.35	49	11	14	22	12	18	13	13	18	11	34	16.6	45.2	6.73	.41
.30	47	10	13	20	9	17	10	11	17	11	20	13.8	16.6	4.07	.29
.25	44	8	10	13	6	15	7	9	15	6	12	10.1	10.9	3.30	.33
.20	42	0	9	12	0	9	6	7	14	4	11	7.2	20.6	4.53	.63
.15	40	0	8	7	0	6	3	3	11	4	9	5.1	12.5	3.53	.69
.10	38	0	5	3	0	1	1	0	10	1	5	2.6	9.4	3.07	1.18
.05	35	0	0	0	0	0	[illegible]	0	7	0	3	1.0	4.8	2.19	2.19
0.00	33	0	0	0	0	0			6	0	0	.6	3.2	1.80	3.00
-.05	31	0	0	0	0	0			2	0	0	.2	.4	.60	3.00

STOP END OF PROGRAM AT STATEMENT 0100 + 00 LINES

APPENDIX B

Tables of longest uninterrupted duration of temperature at or above given values in July (R_m temperature standardization)

LONGEST UNINTERRUPTED DURATION OF TEMPERATURE
AT OR ABOVE GIVEN VALUES, IN JULY (IN HOURS)
R(M) TEMP. STANDARDIZATION

1) BETHEL, ALASKA 1953-1962 (10 YRS)

TEMP'TURE T(M)	DEG	YR= 1	2	3	4	5	6	7	8	9	10	AVRG	VAR	STD DEV	REL STDEV
.45	56	44	19	37	47	23	44	22	69	20	43	36.8	229.1	15.13	.41
.50	58	43	15	19	45	21	19	19	46	18	43	28.8	161.7	12.71	.44
.55	60	20	15	16	19	16	17	15	22	14	18	17.2	5.7	2.40	.13
.60	62	17	13	12	17	14	15	11	20	13	17	14.9	7.0	2.66	.17
.65	63	16	12	11	17	13	14	11	19	12	16	14.1	6.8	2.62	.18
.70	65	15	11	11	14	12	12	9	18	12	16	13.0	6.6	2.56	.19
.75	67	14	10	9	14	10	10	0	15	10	15	10.7	17.8	4.22	.39
.80	69	13	9	8	12	10	10	0	15	10	13	10.0	15.2	3.89	.38
.85	71	12	8	5	12	8	8	0	14	8	13	8.8	15.9	3.99	.45
.90	72	12	7	4	11	7	7	0	12	8	13	8.1	14.8	3.85	.47
.95	74	10	5	1	10	6	4	0	11	5	12	6.4	15.8	3.97	.62
1.00	76	8	0	0	9	3	4	0	9	0	10	4.3	16.6	4.07	.94
1.05	78	4	0	0	6	0	1	0	8	0	9	2.8	11.9	3.45	1.23
1.10	80	0	0	0	1	0	0	0	6	0	4	1.1	4.0	2.02	1.83
1.15	81	0	0	0	0	0	0	0	5	0	1	.6	2.2	1.49	2.49
1.20	83	0	0	0	0	0	0	0	5	0	0	.5	2.2	1.50	3.00

2) BROWNSVILLE, TEXAS 1951-1960 (10 YRS)

TEMP'TURE T(M)	DEG	YR= 1	2	3	4	5	6	7	8	9	10	AVRG	VAR	STD DEV	REL STDEV
.45	83	13	13	19	14	14	11	15	15	12	16	14.2	4.5	2.13	.15
.50	84	12	12	16	12	12	10	13	12	11	14	12.4	2.4	1.56	.12
.55	85	11	11	12	12	11	10	11	11	10	11	11.0	.4	.63	.05
.60	86	11	10	11	11	10	9	10	10	10	10	10.2	.3	.60	.05
.65	88	9	9	10	10	9	6	9	9	9	9	8.9	1.0	1.04	.11
.70	89	8	8	10	10	8	6	9	8	7	9	8.3	1.4	1.18	.14
.75	90	8	7	9	9	7	4	7	6	7	9	7.3	2.2	1.48	.20
.80	91	7	6	9	8	7	4	7	5	6	8	6.7	2.0	1.41	.21
.85	92	6	4	8	8	5	1	6	3	6	7	5.4	4.4	2.10	.39
.90	94	4	2	4	8	0	0	1	0	4	6	2.9	6.8	2.62	.90
.95	95	2	0	4	7	0	0	0	0	2	5	2.0	5.8	2.40	1.20
1.00	96	0	0	0	6	0	0	0	0	0	4	1.0	4.2	2.04	2.04
1.05	97	0	0	0	4	0	0	0	0	0	3	.7	2.0	1.41	2.02
1.10	98	0	0	0	3	0	0	0	0	0	3	.6	1.4	1.20	2.00
1.15	100	0	0	0	1	0	0	0	0	0	0	.1	0.0	.30	3.00

3) CAPE HATTERAS, NO. CAR. 1953-1962 (10 YRS)

TEMP'TURE T(M)	DEG	YR= 1	2	3	4	5	6	7	8	9	10	AVRG	VAR	STD DEV	REL STDEV
.45	76	114	116	119	139	97	66	91	88	205	93	112.8	1315.9	36.27	.32
.50	78	91	64	114	113	46	40	48	20	22	86	64.4	1096.8	33.11	.51
.55	79	71	37	74	67	17	20	47	14	20	38	40.5	491.0	22.15	.54
.60	80	36	17	42	14	15	17	20	13	20	21	21.5	84.6	9.20	.42
.65	81	18	13	19	12	12	16	18	11	16	17	15.2	7.7	2.78	.18
.70	82	15	10	12	10	11	12	11	10	16	14	12.1	4.2	2.07	.17
.75	83	13	9	[illegible]	8	10	11	11	9	11	13	10.6	2.4	1.56	.14
.80	84	11	7			8	11	10	8	10	11	9.2	2.9	1.72	.18
.85	86	7	4			3	8	7	5	9	10	5.7	8.4	2.90	.50
.90	87	3	2			3	7	6	3	7	9	4.1	7.8	2.80	.68
.95	88	0	1			3	2	3	1	7	6	2.3	5.6	2.36	1.02
1.00	89	0	0	0	0	1	1	1	0	4	5	1.2	2.9	1.72	1.43
1.05	90	0	0	0	0	1	0	0	0	3	2	.6	1.0	1.01	1.69
1.10	91	0	0	0	0	0	0	0	0	1	1	.2	.1	.40	2.00

4) CARIBOU, MAINE 1953-1962 (10 YRS)

TEMP'TURE T(M)	DEG	YR= 1	2	3	4	5	6	7	8	9	10	AVRG	VAR	STD DEV	REL STDEV
.45	64	87	19	69	15	37	39	92	38	86	17	49.9	849.8	29.15	.58
.50	66	45	16	46	14	35	38	65	19	63	16	35.7	332.8	18.24	.51
.55	68	21	14	44	13	14	14	21	15	61	12	22.9	242.0	15.55	.67
.60	70	19	11	42	12	11	14	16	13	20	12	17.0	78.6	8.86	.52
.65	73	15	10	18	11	11	11	15	11	13	10	12.5	6.4	2.53	.20
.70	75	14	9	16	10	9	10	13	10	11	8	11.0	5.8	2.40	.21
.75	77	13	7	14	8	7	10	12	8	11	6	9.6	7.0	2.65	.27
.80	79	11	6	13	8	6	8	10	6	9	6	8.3	5.4	2.32	.28
.85	81	9	1	12	1	6	8	10	2	9	4	6.2	14.3	3.78	.61
.90	84	8	0	10	0	4	3	9	0	6	0	4.0	14.6	3.82	.95
.95	86	6	0	10	0	1	2	7	0	3	0	2.9	11.4	3.38	1.16
1.00	88	4	0	9	0	0	0	5	0	1	0	1.9	8.6	2.94	1.55
1.05	90	1	0	8	0	0	0	3	0	0	0	1.2	5.9	2.44	2.03
1.10	92	0	0	4	0	0	0	0	0	0	0	.4	1.4	1.20	3.00
1.15	95	0	0	1	0	0	0	0	0	0	0	.1	0.0	.30	3.00

5) DAYTON, OHIO 1951-1960 (10 YRS)

TEMP'TURE T(M)	DEG	YR= 1	2	3	4	5	6	7	8	9	10	AVRG	VAR	STD DEV	REL STDEV
.45	74	40	45	24	43	67	41	46	19	22	19	36.6	214.6	14.65	.40
.50	76	19	21	19	20	29	40	22	16	18	16	22.0	48.4	6.95	.31
.55	78	15	19	18	20	23	17	17	14	13	13	16.9	9.4	3.08	.18
.60	80	13	17	16	17	18	17	17	12	12	12	15.1	5.6	2.38	.15
.65	82	11	14	14	15	14	16	13	11	10	10	12.6	4.1	2.03	.15
.70	84	10	14	12	14	13	13	11	9	8	8	11.2	4.9	2.22	.19
.75	86	8	11	11	11	12	11	10	8	7	6	9.5	3.8	1.96	.20
.80	88	5	9	10	11	12	9	7	2	3	3	7.1	11.8	3.44	.48
.85	90	3	8	8	11	9	8	6	0	0	0	5.3	15.8	3.97	.75
.90	92	0	5	7	10	3	6	4	0	0	0	3.5	11.2	3.35	.95
.95	94	0	5	4	8	2	4	0	0	0	0	2.3	7.2	2.68	1.16
1.00	96	0	0	0	8	0	2	0	0	0	0	1.0	5.8	2.40	2.40
1.05	98	0	0	0	6	0	0	0	0	0	0	.6	3.2	1.80	3.00
1.10	100	0	0	0	4	0	0	0	0	0	0	.4	1.4	1.20	3.00

6) DENVER, COLORADO 1951-1960 (10 YRS)

TEMP'TURE T(M)	DEG	YR= 1	2	3	4	5	6	7	8	9	10	AVRG	VAR	STD DEV	REL STDEV
.45	72	19	21	19	21	21	19	19	18	17	19	19.3	1.6	1.26	.06
.50	75	17	18	16	19	17	17	15	16	15	16	16.6	1.4	1.20	.07
.55	77	15	17	16	19	15	15	15	14	13	15	15.4	2.4	1.56	.10
.60	79	14	16	14	17	14	14	13	13	13	14	14.2	1.5	1.24	.08
.65	81	13	12	14	15	12	12	13	13	12	13	12.9	.8	.94	.07
.70	83	13	11	11	14	12	9	11	12	11	12	11.6	1.6	1.28	.11
.75	85	13	10	11	13	11	7	10	12	10	11	10.8	2.7	1.66	.15
.80	87	11	9	9	12	9	7	9	10	7	10	9.3	2.2	1.48	.15
.85	90	8	7	8	11	8	4	8	7	6	8	7.5	2.8	1.68	.22
.90	92	7	5	5	10	7	0	6	2	4	6	5.2	6.9	2.63	.50
.95	94	3	1	0	8	5	0	0	1	2	3	2.3	6.0	2.45	1.06
1.00	96	1	0	0	7	2	0	0	0	0	0	1.0	4.4	2.09	2.09
1.05	98	0	0	0	5	0	0	0	0	0	0	.5	2.2	1.50	3.00
1.10	100	0	0	0	3	0	0	0	0	0	0	.3	.8	.90	3.00

7) EDMONTON, ALBERTA 1957-1965 (8 YRS)

TEMP'TURE T(M)	DEG	YR= 1	2	3	4	5	6	7	8	9	10
.45	63	42	65		47	43	20	44	62		
.50	65	39	45		22	21	16	41	39		
.55	67	18	23		20	20	15	20	37		
.60	70	17	16		18	16	13	17	36		
.65	72	12	14		16	14	11	16	20		
.70	75	10	13		15	12	9	16	16		
.75	77	10	11		13	10	6	15	14		
.80	79	8	10		13	9	3	14	12		
.85	82	6	8		10	8	0	9	9		
.90	84	6	6		8	7	0	7	8		
.95	87	2	0		5	5	0	2	8		
1.00	89	0	0		0	5	0	0	4		
1.05	91	0	0		0	3	0	0	1		

8) HONOLULU, HAWAII 1951-1960 (10 YRS)

TEMP:TURE T(M)	DEG	YR= 1	2	3	4	5	6	7	8	9	10	AVRG	VAR	STD DEV	REL STDEV
.45	76	94	20	23	23	15	43	116	40	101	121	59.6	1674.4	40.91	.68
.50	77	63	16	19	17	12	17	27	18	55	42	28.6	297.0	17.23	.60
.55	78	42	13	13	12	11	13	21	14	19	22	18.0	77.8	8.82	.49
.60	78	42	13	13	12	11	13	21	14	19	22	18.0	77.8	8.82	.49
.65	79	18	10	12	11	10	12	15	12	16	16	13.2	7.1	2.67	.20
.70	80	12	10	10	10	9	11	11	10	13	11	10.7	1.2	1.10	.10
.75	81	10	9	8	9	8	10	10	9	11	10	9.4	.8	.91	.09
.80	81	10	9	8	9	8	10	10	9	11	10	9.4	.8	.91	.09
.85	82	10	7	7	8	7	9	8	8	10	9	8.3	1.2	1.10	.13
.90	83	9	5	4	6	4	8	7	8	10	7	6.8	3.7	1.93	.28
.95	83	9	5	4	6	4	6	7	8	10	7	6.8	3.7	1.93	.28
1.00	84	7	3	3	3	2	7	4	6	9	6	5.0	4.8	2.19	.43
1.05	85	3	1	0	1	0	3	2	2	6	4	2.2	3.1	1.77	.80
1.10	85	3	0	0	0	0	1	2	2	6	4	1.8	3.7	1.93	1.07
1.15	86	1	0	0	0	0	1	1	1	5	1	1.0	2.0	1.41	1.41
1.20	87	1	0	0	0	0	0	0	1	5	0	.7	2.2	1.48	2.12

9) KEY WEST, FLORIDA 1960-1964 (5 YRS)

TEMP'TURE T(M)	DEG	YR= 1	2	3	4	5	6	7	8	9	10	AVRG	VAR	STD DEV	REL STDEV
.45	82	120	383	288	72	143						201.2	13452.	116.0	.57
.50	83	93	72	288	39	86						115.6	7775.4	88.17	.76
.55	83	93	72	288	39	86						115.6	7775.4	88.17	.76
.60	84	43	20	89	20	19						38.2	726.9	26.96	.70
.65	85	15	12	20	16	14						15.4	7.0	2.65	.17
.70	86	12	10	13	11	10						11.2	1.3	1.16	.10
.75	87	11	9	11	10	10						10.2	.5	.74	.07
.80	88	8	7	10	8	8						8.2	.9	.97	.11
.85	89	6	5	8	7	6						6.4	1.0	1.01	.15
.90	90	2	2	6	5	3						3.6	2.6	1.62	.45
.95	91	2	0	6	2	0						2.0	4.8	2.19	1.09
1.00	92	0	0	4	1	0						1.0	2.4	1.54	1.54
1.05	93	0	0	1	1	0						.4	.2	.48	1.22

10) KNOXVILLE, TENNESSEE 1951-1960 (10 YRS)

TEMP'TURE T(M)	DEG	YR= 1	2	3	4	5	6	7	8	9	10	AVRG	VAR	STD DEV	REL STDEV
.45	77	21	22	32	46	18	18	35	43	22	18	27.5	103.2	10.16	.36
.50	79	15	20	16	44	18	16	18	16	18	15	19.6	68.4	8.27	.42
.55	81	14	18	15	42	15	16	15	14	14	13	17.6	67.8	8.23	.46
.60	83	12	18	12	32	12	14	12	12	12	13	14.9	35.6	5.97	.40
.65	84	11	17	11	18	11	13	11	12	11	11	12.6	6.4	2.53	.20
.70	86	10	13	9	15	11	11	10	8	9	10	10.6	3.8	1.95	.18
.75	88	9	13	8	12	10	9	7	6	8	7	8.9	4.4	2.11	.23
.80	90	8	13	[illegible]	9	9	9	7	5	4	6	7.6	6.0	2.45	.32
.85	92	6	12	5	8	7	4	4	3	1	3	5.3	8.8	2.96	.56
.90	93	4	11	3	7	6	2	3	2	0	0	3.8	10.3	3.21	[illegible]
.95	95	3	9	3	7	3	0	1	0	0	0	2.6	9.0	3.00	1.1[illegible]
1.00	97	2	8	2	5	0	0	0	0	0	0	1.7	6.8	2.60	1.53
1.05	95	0	6	0	3	0	0	0	0	0	0	.9	3.6	1.92	2.13
1.10	101	0	5	0	0	0	0	0	0	0	0	.5	2.2	1.50	3.00
1.15	102	0	5	0	0	0	0	0	0	0	0	.5	2.2	1.50	3.00

11) MIAMI, FLORIDA 1951-1960 (10 YRS)

TEMP'TURE T(M)	DEG	YR= 1	2	3	4	5	6	7	8	9	10	AVRG	VAR	STD DEV	REL STDEV
.45	79	42	75	68	92	49	92	47	96	201	18	69.9	823.0	28.68	.41
.50	81	23	57	42	47	18	91	22	40	17	70	42.7	539.6	23.22	.54
.55	82	20	23	41	26	18	43	18	20	13	19	24.1	90.4	9.51	.39
.60	83	15	19	17	22	12	18	15	14	13	17	16.2	8.1	2.85	.17
.65	84	12	16	14	17	11	15	12	12	11	16	13.6	4.6	2.15	.15
.70	85	11	13	11	14	10	11	11	11	10	12	11.4	1.4	1.20	.10
.75	86	10	11	10	12	8	10	10	10	7	10	9.8	1.7	1.32	.13
.80	87	8	10	9	11	8	9	10	9	7	10	9.1	1.2	1.13	.12
.85	88	7	9	8	10	6	8	8	7	4	10	7.7	3.0	1.73	.22
.90	89	6	7	7	9	3	7	4	6	2	8	5.9	4.4	2.11	.35
.95	90	2	5	5	4	2	6	3	4	2	5	3.8	1.9	1.40	.36
1.00	91	1	4	5	4	1	4	1	2	1	4	2.7	2.4	1.55	.57
1.05	92	0	3	2	4	0	1	1	0	0	1	1.2	1.7	1.32	1.10
1.10	93	0	2	1	1	0	1	0	0	0	0	.5	.4	.67	1.34

12) MOBILE, ALABAMA 1951-1960 (10 YRS)

TEMP'TURE T(M)	DEG	YR= 1	2	3	4	5	6	7	8	9	10	AVRG	VAR	STD DEV	REL STDEV
.45	82	18	16	14	14	12	12	15	13	11	18	14.3	5.4	2.32	.16
.50	83	17	14	12	12	11	11	15	12	11	17	13.2	5.1	2.27	.17
.55	84	16	14	12	12	10	10	13	10	8	14	11.9	5.2	2.30	.19
.60	86	12	13	11	10	9	9	11	9	6	12	10.2	3.7	1.93	.19
.65	87	11	11	10	9	7	9	10	7	6	11	9.1	3.0	1.75	.19
.70	89	10	11	8	8	5	7	8	5	4	9	7.5	4.6	2.15	.28
.75	90	10	11	7	8	4	5	8	4	4	8	6.9	5.8	2.42	.35
.80	91	8	9	6	8	2	5	7	3	3	8	5.9	5.6	2.38	.40
.85	93	8	8	3	5	2	2	6	0	1	6	4.1	7.4	2.73	.66
.90	94	6	8	2	3	0	1	5	0	0	5	3.0	7.4	2.72	.90
.95	96	3	7	1	2	0	0	4	0	0	3	2.0	4.8	2.19	1.09
1.00	97	1	6	1	0	0	0	1	0	0	0	.9	3.0	1.75	1.95
1.05	98	0	5	0	0	0	0	0	0	0	0	.5	2.2	1.50	3.00
1.10	100	0	5	0	0	0	0	0	0	0	0	.5	2.2	1.50	3.00
1.15	101	0	4	0	0	0	0	0	0	0	0	.4	1.4	1.20	3.00
1.20	103	0	2	0	0	0	0	0	0	0	0	.2	.3	.60	3.00

13) PHOENIX, ARIZONA 1951-1960 (10 YRS)

TEMP'TURE T(M)	DEG	YR= 1	2	3	4	5	6	7	8	9	10	AVRG	VAR	STD DEV	REL STDEV
.45	90	18	18	19	22	16	17	19	21	21	19	19.0	3.2	1.78	.09
.50	92	18	17	15	20	14	14	18	19	19	18	17.2	4.1	2.03	.11
.55	94	15	16	14	16	13	13	17	18	17	18	15.7	3.2	1.79	.11
.60	96	13	15	13	15	12	11	14	17	16	14	14.0	3.0	1.73	.12
.65	98	13	13	12	12	9	10	12	15	12	12	12.0	2.4	1.54	.12
.70	100	11	11	10	11	7	9	12	15	11	10	10.7	3.8	1.95	.18
.75	102	9	10	10	10	7	9	9	12	10	9	9.5	1.4	1.20	.12
.80	104	8	8	8	8	5	7	9	11	8	8	8.0	2.0	1.41	.17
.85	106	7	7	8	7	2	6	7	10	6	6	6.6	3.6	1.90	.28
.90	108	6	7	6	5	0	4	6	8	5	4	5.1	4.2	2.07	.40
.95	110	3	3	4	5	0	1	5	8	3	1	3.3	5.0	2.23	.67
1.00	112	0	0	1	2	0	0	3	7	0	0	1.3	4.6	2.14	1.65
1.05	114	0	0	0	0	0	0	0	6	0	0	.6	3.2	1.80	3.00
1.10	116	0	0	0	0	0	0	0	4	0	0	.4	1.4	1.20	3.00

14) PONAPE IS., PACIFIC OCN. 1960-1964 (5 YRS)

TEMP'TURE T(M)	DEG	YR= 1	2	3	4	5	6	7	8	9	10	AVRG	VAR	STD DEV	REL STDEV
.45	79	70	23	35	24	24						35.2	322.1	17.94	.50
.50	80	36	23	18	20	23						24.0	39.6	6.29	.26
.55	81	25	20	17	13	13						17.6	20.6	4.54	.25
.60	82	17	19	13	11	13						14.6	8.6	2.93	.20
.65	83	11	14	10	10	10						11.0	2.4	1.54	.14
.70	84	10	10	9	10	9						9.6	.2	.48	.05
.75	85	10	10	9	10	8						9.4	.6	.80	.08
.80	86	8	9	6	9	6						7.6	1.8	1.35	.17
.85	87	6	5	4	6	5						5.2	.5	.74	.14
.90	88	4	2	2	3	2						2.6	.6	.80	.30
.95	89	1	1	0	2	1						1.0	.4	.63	.63
1.00	90	0	0	0	1	0						.2	.1	.40	2.00

15) ST. PAUL IS., ALASKA 1962-1964 (3 YRS)

TEMP·TURE T(M)	DEG	YR= 1	2	3
.45	46	140	25	24
.50	47	129	17	13
.55	48	84	12	10
.60	48	84	12	10
.65	49	58	8	7
.70	50	53	6	6
.75	51	16	3	5
.80	52	16	1	2
.85	53	16	0	1
.90	54	14	0	0
.95	55	12	0	0
1.00	56	8	0	0
1.05	57	8	0	0
1.10	58	6	0	0
1.15	59	3	0	0
1.20	60	2	0	0

16) SALT LAKE CITY, UTAH 1951-1960 (10 YRS)

TEMP·TURE T(M)	DEG	YR= 1	2	3	4	5	6	7	8	9	10	AVRG	VAR	STD DEV	REL STDEV
.45	73	46	40	90	71	43	65	39	18	41	70	52.3	400.4	20.01	.38
.50	76	31	36	70	42	20	60	23	17	21	23	34.3	294.4	17.15	.50
.55	78	20	17	68	19	19	44	20	14	18	22	26.1	256.2	16.00	.61
.60	81	15	16	17	16	15	22	19	14	14	19	16.7	6.0	2.45	.14
.65	83	15	12	13	14	14	21	16	13	13	17	14.8	6.3	2.52	.17
.70	86	12	10	12	12	12	17	11	12	11	15	12.4	3.8	1.95	.15
.75	88	12	9	11	12	11	13	11	11	11	13	11.4	1.2	1.11	.09
.80	91	11	9	9	10	9	11	9	9	9	11	9.7	.8	.90	.09
.85	93	9	8	8	9	9	10	8	8	9	10	8.8	.5	.74	.08
.90	96	6	6	6	7	7	8	6	6	7	9	6.8	.9	.97	.14
.95	99	2	1	2	3	5	5	1	1	2	7	2.9	3.8	1.97	.68
1.00	101	0	0	0	1	4	0	0	0	0	5	1.0	3.2	1.78	1.78

17) SAN DIEGO, CALIF 1951-1960 (10 YRS)

TEMP·TURE T(M)	DEG	YR= 1	2	3	4	5	6	7	8	9	10	AVRG	VAR	STD DEV	REL STDEV
.45	70	17	17	69	69	38	12	18	41	88	238	60.7	4123.6	64.21	1.05
.50	71	16	14	21	22	21	11	17	21	86	68	29.7	586.8	24.22	.81
.55	72	14	14	18	17	11	10	16	17	43	44	20.4	139.4	11.80	.57
.60	73	13	11	18	16	10	9	15	13	18	20	14.3	12.4	3.52	.24
.65	75	11	1.	10	13	8	7	13	11	16	15	11.5	7.2	2.69	.23
.70	76	11	10	10	11	4	7	12	10	15	13	10.3	8.4	2.90	.2C
.75	77	9	8	8	11	3	3	12	9	15	13	9.1	13.8	3.72	.40
.80	78	9	7	7	10	3	2	10	8	14	11	8.1	11.6	3.41	.42
.85	79	6	7	7	10	1	0	8	3	12	10	6.4	14.2	3.77	.58
.90	81	4	2	3	7	0	0	7	2	10	9	4.6	11.6	3.41	.74
.95	82	3	2	4	4	0	0	5	1	10	7	3.6	9.0	3.00	.83
1.00	83	2	1	0	3	0	0	5	0	8	7	2.6	8.4	2.90	1.11
1.05	84	1	0	0	0	0	0	4	0	8	6	1.9	8.0	2.84	1.49
1.10	85	0	0	0	0	0	0	1	0	8	6	1.5	7.8	2.80	1.86
1.15	87	0	0	0	0	0	0	0	0	8	3	1.1	6.0	2.46	2.24
1.20	88	0	0	0	0	0	0	0	0	6	2	.8	3.3	1.83	2.29

18) SAN FRANCISCO, CALIF.   1951-1960 (10 YRS)

TEMP:TURE T(M)	DEG	YR= 1	2	3	4	5	6	7	8	9	10	AVRG	VAR	STD DEV	REL STDEV
.38	63	13	14	10	13	11	13	36	14	16	11	15.1	51.2	7.16	.47
.41	64	13	13	10	13	11	12	16	12	15	11	12.6	3.0	1.74	.13
.43	65	12	13	10	13	9	12	12	11	14	10	11.6	2.2	1.49	.12
.49	67	12	13	8	12	7	12	11	10	13	10	10.8	3.7	1.93	.17
.51	68	10	12	8	11	7	11	10	8	13	9	9.9	3.2	1.81	.18
.57	70	10	11	7	11	6	10	10	7	13	8	9.3	4.4	2.10	.22
.59	71	10	10	7	11	5	10	9	6	12	8	8.8	4.5	2.13	.24
.62	72	8	10	7	11	3	10	9	5	11	8	8.2	6.1	2.48	.30
.68	74	7	9	6	8	0	9	8	5	10	6	6.8	7.3	2.71	.39
.70	75	5	6	6	7	0	8	8	4	10	6	6.0	6.6	2.56	.42
.76	77	4	5	5	7	0	5	7	3	9	4	4.9	5.4	2.34	.47
.78	78	4	5	3	6	0	5	4	2	9	4	4.2	5.1	2.27	.54
.81	79	1	5	2	6	0	5	4	1	8	3	3.5	5.8	2.41	.69
.86	81	0	3	0	3	0	3	3	0	8	1	2.1	5.6	2.38	1.13
.89	82	0	3	0	3	0	3	2	0	8	0	1.9	5.8	2.42	1.27
.95	84	0	3	0	1	0	0	0	0	6	0	1.0	3.6	1.89	1.89
1.05	88	0	0	0	0	0	0	0		5	0	.5	2.2	1.50	3.00
1.11	90	0	0	0	0	0	0			3	0	.3	.8	.90	3.00
1.16	92	0	0	0	0	0	0	0		2	0	.2	.3	.60	3.00
1.22	94	0	0	0	0	0	0	0		2	0	.2	.3	.60	3.00

19) SAVANNAH, GEORGIA   1951-1960 (10 YRS)

TEMP:TURE T(M)	DEG	YR= 1	2	3	4	5	6	7	8	9	10	AVRG	VAR	STD DEV	REL STDEV
.45	81	17	21	15	20	14	15	15	16	15	19	16.7	5.4	2.32	.13
.50	83	14	17	12	18	12	13	13	14	13	16	14.2	3.9	1.98	.14
.55	84	12	15	12	16	12	13	13	13	11	14	13.1	2.0	1.44	.11
.60	86	11	14	10	14	9	10	11	12	10	12	11.3	2.6	1.61	.14
.65	87	11	12	10	14	9	9	10	11	10	12	10.8	2.1	1.46	.13
.70	89	9	12	8	11	7	8	8	10	10	11	9.4	2.4	1.56	.16
.75	90	9	10	8	11	6	8	7	10	8	9	8.6	2.0	1.42	.16
.80	92	7	9	8	9	3	7	5	8	6	9	7.1	3.4	1.86	.26
.85	93	6	8	6	9	1	5	5	7	5	8	6.0	4.6	2.14	.35
.90	95	4	7	5	6	0	3	1	5	1	7	3.9	5.8	2.42	.62
.95	97	3	6	0	4	0	0	0	5	0	4	2.2	5.3	2.31	1.05
1.00	98	2	6	0	1	0	0	0	3	0	2	1.4	3.4	1.85	1.32
1.05	100	0	4	0	0	0	0	0	0	0	0	.4	1.4	1.20	3.00
1.10	101	0	3	0	0	0	0	0	0	0	0	.3	.8	.90	3.00
1.15	103	0	1	0	0	0	0	0	0	0	0	.1	0.0	.30	3.00

20) SEATTLE, WASH.   1951-1960 (10 YRS)

TEMP:TURE T(M)	DEG	YR= 1	2	3	4	5	6	7	8	9	10	AVRG	VAR	STD DEV	REL STDEV
.45	68	19	18	15	10	12	19	14	21	19	19	16.6	11.8	3.44	.20
.50	70	19	15	12	9	11	17	13	20	18	17	15.1	12.2	3.50	.23
.55	72	17	13	12	8	10	15	11	18	15	15	13.4	9.0	3.00	.22
.60	74	17	12	11	8	9	15	9	17	15	14	12.7	10.2	3.19	.25
.65	75	16	12	10	6	8	14	9	17	15	13	12.0	12.0	3.46	.28
.70	77	14	10	9	4	6	13	7	15	13	13	10.4	12.8	3.58	.34
.75	79	11	10	8	4	5	13	5	15	11	12	9.4	12.6	3.55	.37
.80	81	10	9	6	0	2	11	2	12	9	11	7.2	17.3	4.16	.57
.85	83	10	8	5	0	0	10	0	11	8	9	6.1	18.2	4.27	.70
.90	84	10	7	4	0	0	9	0	9	7	9	5.5	15.4	3.93	.71
.95	86	8	6	4	0	0	9	0	8	7	8	5.0	12.4	3.52	.70
1.00	88	6	3	0	0	0	7	0	7	5	6	3.4	8.8	2.97	.87
1.05	90	6	0	0	0	0	7	0	7	3	6	2.9	9.4	3.08	1.06
1.10	92	3	0	0	0	0	4	0	6	0	3	1.6	4.4	2.10	1.31
1.15	93	2	0	0	0	0	1	0	5	0	0	.8	2.3	1.53	1.92
1.20	95	0	0	0	0	0	0	0	3	0	0	.3	.8	.90	3.00

21) SPOKANE, WASH. 1951-1960 (10 YRS)

TEMP'TURE T(M)	DEG	YR= 1	2	3	4	5	6	7	8	9	10	AVRG	VAR	STD DEV	REL STDEV
.45	69	20	20	21	17	43	44	19	42	66	65	35.7	327.6	18.10	.50
.50	72	17	18	19	17	21	40	16	20	21	20	20.9	43.2	6.57	.31
.55	75	17	17	17	13	19	20	15	16	18	17	16.9	3.4	1.86	.11
.60	77	13	16	15	12	16	19	13	15	16	17	15.2	3.9	1.98	.13
.65	80	12	14	14	11	13	14	12	13	15	14	13.2	1.3	1.16	.08
.70	82	11	13	13	9	13	12	10	12	14	13	12.0	2.2	1.48	.12
.75	85	11	11	11	9	11	11	8	11	12	12	10.7	1.4	1.18	.11
.80	88	9	9	9	7	9	10	6	9	10	10	8.8	1.5	1.24	.14
.85	90	8	9	8	6	9	9	5	8	10	10	8.2	2.3	1.53	.18
.90	93	7	7	6	2	7	7	0	5	8	10	5.9	7.6	2.77	.47
.95	95	6	6	4	0	6	4	0	1	8	8	4.3	8.4	2.90	.67
1.00	98	1	1	0	0	1	0	0	0	5	6	1.4	4.4	2.10	1.50
1.05	101	0	0	0	0	0	[illegible]				1	.1	0.0	.30	3.00

22) SPRINGFIELD, MO. 1951-1960 (10 YRS)

TEMP'TURE T(M)	DEG	YR= 1	2	3	4	5	6	7	8	9	10	AVRG	VAR	STD DEV	REL STDEV
.45	76	18	22	36	94	20	23	21	18	18	18	28.8	498.7	22.33	.77
.50	78	15	20	35	93	17	22	17	16	15	18	26.8	518.3	22.76	.84
.55	80	14	18	19	42	15	21	15	13	13	16	18.6	67.0	8.18	.44
.60	82	13	16	16	20	13	16	14	12	12	14	14.6	5.4	2.33	.15
.65	84	11	14	16	19	13	13	12	10	11	14	13.3	6.4	2.53	.19
.70	86	10	14	14	18	10	10	11	9	9	13	11.8	7.5	2.74	.23
.75	88	8	12	13	16	10	9	9	8	6	11	10.2	7.5	2.74	.26
.80	90	7	10	11	14	9	8	9	6	5	11	9.0	6.4	2.52	.28
.85	92	4	9	9	14	8	7	8	1	3	8	7.1	12.0	3.47	.48
.90	94	0	8	7	11	5	4	6	0	0	7	4.8	12.9	3.60	.75
.95	96	0	6	6	11	3	0	3	0	0	4	3.3	11.8	3.43	1.04
1.00	98	0	5	3	10	0	0	2	0	0	2	2.2	9.3	3.05	1.39
1.05	100	0	4	0	9	0	0	0	0	0	0	1.3	8.0	2.83	2.17
1.10	102	0	0	0	8	0	0	0	0	0	0	.8	5.7	2.40	3.00
1.15	104	0	0	0	7	0	0	0	0	0	0	.7	4.4	2.10	3.00

23) YUMA, ARIZONA 1953-1962 (10 YRS)

TEMP'TURE T(M)	DEG	YR= 1	2	3	4	5	6	7	8	9	10	AVRG	VAR	STD DEV	REL STDEV
.45	90	22	20	22	21	22	20	42	23	20	19	23.1	41.0	6.41	.27
.50	92	20	17	17	19	21	17	21	21	17	16	18.6	3.6	1.90	.10
.55	94	16	15	15	19	18	16	19	18	14	13	16.3	4.0	2.00	.12
.60	97	13	12	14	14	13	14	17	15	12	12	13.6	2.2	1.49	.11
.65	99	12	13	12	11	13	13	13	13	11	10	12.1	1.0	1.04	.08
.70	101	11	11	11	9	12	12	10	11	10	8	10.5	1.4	1.20	.11
.75	104	9	10	9	7	11	11	9	9	8	7	9.0	1.8	1.34	.14
.80	106	8	9	9	7	9	9	9	8	8	6	8.2	.9	.97	.11
.85	108	6	8	6	5	8	9	7	7	7	5	6.8	1.5	1.24	.18
.90	110	3	7	3	4	8	8	6	6	6	2	5.3	4.2	2.05	.38
.95	113	0	5	0	0	6	6	4	3	2	0	2.6	5.8	2.41	.92
1.00	115	0	2	0	0	5	5	0	0	0	0	1.2	3.9	1.98	1.65
1.05	117	0	0	0	0	4	1	0	0	0	0	.5	1.4	1.20	2.40

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13. ABSTRACT

The statistical distribution of the longest uninterrupted duration of temperature above or below any given value was studied from hourly temperature records from 25 stations. The purpose was to examine the temperature duration variable from different aspects and to explore the problems involved in the development of a general distribution-model. Besides its value for the development of an empirical model, this information is also essential for the study of theoretical models.

The distribution of temperature durations has been derived for some types of stations and can be used to make accurate predictions. The variability in these distributions has been reduced almost to the natural limit set by the variability in time inherent to durations in nature. This was achieved by reducing actual temperature values to a uniform standard scale and by stratifying the sample of stations.

The distributional patterns of durations of high temperatures and of low temperatures are shown to be quite different from each other. The latter are considerably longer and, in winter, much more variable from year to year. Such differences must be reflected in any distribution model to be suggested, whether empirical or with some other basis.

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